# COMBUSTION

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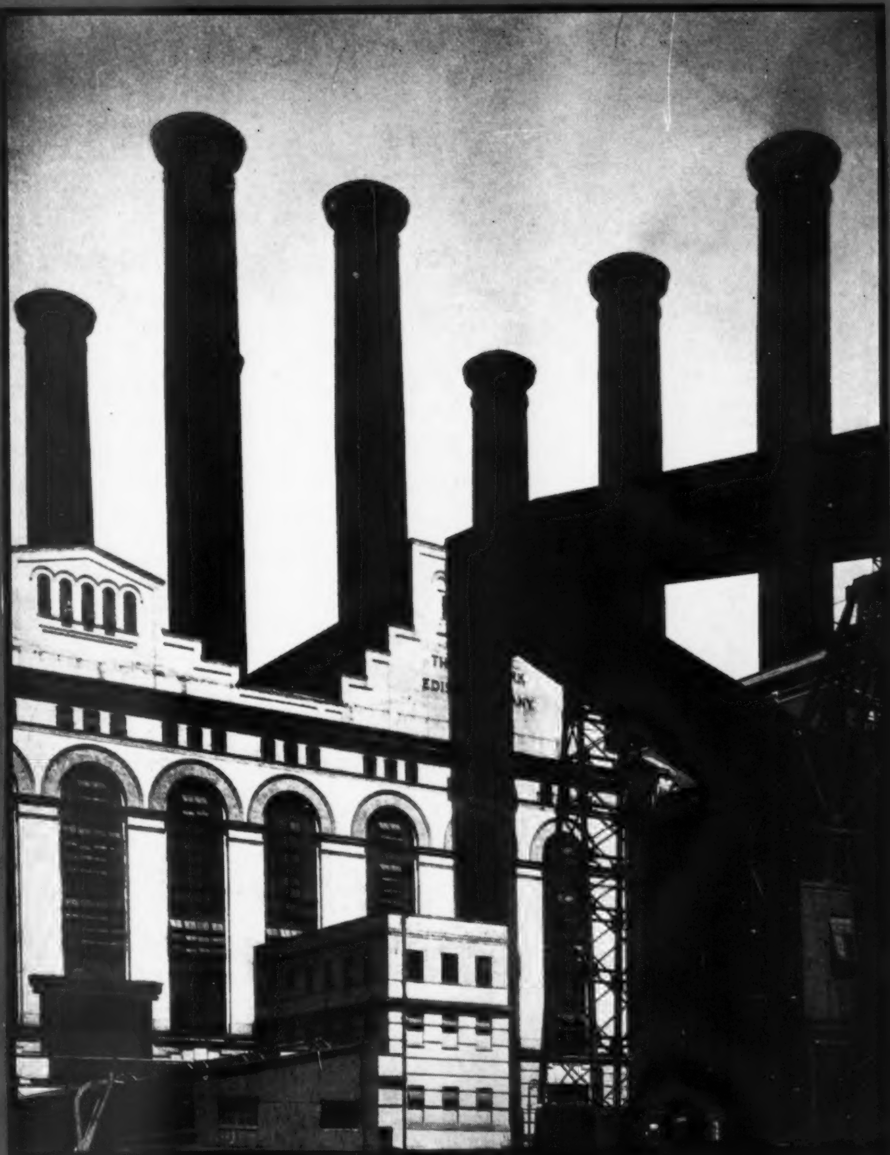


NEW YORK EDISON COMPANY, EAST 40th STREET STATION

**Performance of a Pulverized-Coal-Fired Boiler Using the Unit System and Tangential Firing**

By JOHN J. GROB and JOSEPH GERSHBERG

**Removal of Moisture from Steam**

By C. E. JOOS

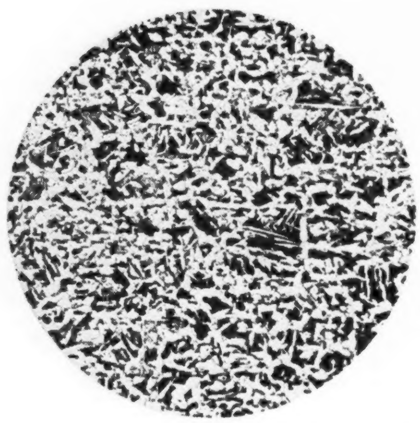
OTHER ARTICLES IN THIS ISSUE BY

G. MINGLE • WM. L. DeBAUFRE • A. W. PATTERSON, JR. • B. J. CROSS • DAVID BROWNLIE

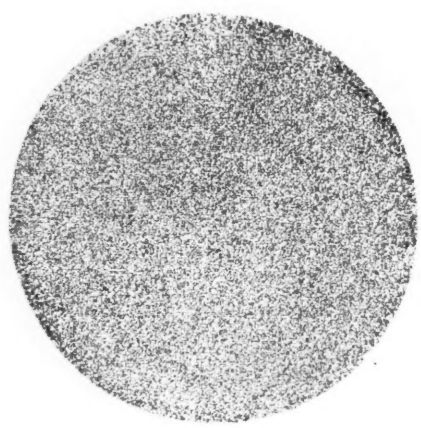
# COMBUSTION ENGINEERING CORPORATION

# ANNOUNCES

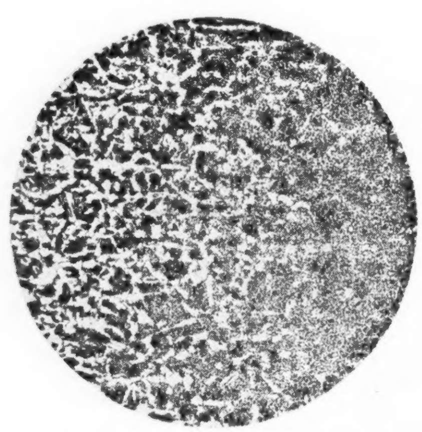
**The receipt of the following contracts for**
**FUSION-WELDED BOILER DRUMS**
**from subsidiaries of**
**General Motors Corporation**



Original metal adjacent to weld magnified 250 times. This is a normal grain structure for steel boiler plates.



H-W-W High-Pressure Weld metal magnified 250 times. Note exceedingly fine grain structure.



Junction between original plate and H-W-W High-Pressure Weld metal, showing excellent fusion and complete welding. Note absence of line of junction.

**For Fisher Body Corporation —**
54 in. dia. drum for 722 hp. boiler,
200 lb. steam pressure.

**For Fisher Lumber Corporation —**
60 in. dia. drum for 887 hp. boiler,
200 lb. steam pressure.

These drums are being fabricated in our Hedges-Walsh-Weidner Shops at Chattanooga, Tenn., by the H-W-W High-Pressure, Fusion-Welding Process. This process is the result of three years' intensive research and development work which has included every practical method of weld testing. In all respects the results have equalled or exceeded the proposed A. S. M. E. Code for welded boiler drums. Full size drums, tested to destruction, have proved the welded seams to have a strength as great, or greater than, the plate itself.

**Facts concerning H-W-W High-Pressure Welding Process**

Rods used made to our special specifications, to insure uniform high quality of deposited metal.

Only men trained in our welding technique and of proved qualifications are employed in welding.

Procedure control, specifications of rod and facilities used produce welds of unquestionable character.

Ductility of deposited metal slightly greater than that of boiler plate. Ductility of adjacent plate and remote plate unimpaired by weld.

Tensile strength slightly greater than that of boiler plate, but kept in same range as boiler plate.

Deposited metal in weld fused with base metal, without destroying grain structure of base metal.

All drums subjected to hydrostatic test.

All drums are stress relieved in a special furnace of sufficient size to handle practically any drum that can be shipped.

Seams radiographed by powerful new X-ray of latest design capable of X-raying material 3 in. thick and adaptable for X-raying even greater thicknesses.

NEW LITERATURE WILL BE SENT UPON REQUEST

*Pending the adoption of the proposed A. S. M. E. Code for welded boiler drums, this construction is offered in non-code states.*

**COMBUSTION ENGINEERING CORPORATION**
**200 Madison Avenue New York**

# COMBUSTION

VOLUME TWO • NUMBER TWELVE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CHARLES MCDONOUGH, *Business Manager* — CARL STRIPE, *Editor* — H. STUART ACHESON, *General Representative*

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# The *Balanced Valve*

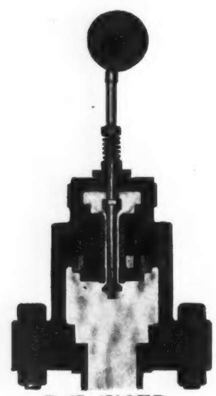
MASTER
MODEL "K-2"

## —another exclusive feature in BAYER SOOT BLOWERS

Though the time required to open one valve and complete a single blowing operation is small, when multiplied by the number of elements and the number of operations a year, the greatly reduced manual effort and time saved with Bayer Balanced Valves means a considerable saving.

As may be seen from the illustration of the Bayer Valve in balanced position, the force required for opening the valve is considerably reduced. Actually the Bayer valve opens against a force of only 21 pounds with a boiler pressure of 200 pounds per square inch. A similar valve without the balanced feature would require 706 pounds.

It does not take a diagram for any engineer to realize the time saved and the great reduction of wear and tear on blower heads where this exclusive Bayer feature is used.



*BALANCED*

## BAYER CHROMITE *non-corrosive elements*

A BAYER for every type of boiler

"CHROMITE" is the trade name adopted by the Bayer Company and means that Bayer CHROMITE Air-Cooled Soot Blower Elements are fabricated from Chromium Iron alloy into continuous lengths of rolled tubing (not cast).

The heat resistance qualities of CHROMITE combined with air-cooling produces a soot-blower element that is immune to oxidation and warping even when exposed to temperatures as high as 2650 degrees F.

**Our experience with effective soot-blower installations may be of help to you. We will be glad to answer your questions.**

THE BAYER COMPANY
**1508 Grand Blvd., St. Louis, Mo.**

COMBUSTION

VOLUME 2 JUNE 1931 NUMBER 12

# Flexibility In Boiler Furnace Design

FRANK S. COLLINGS

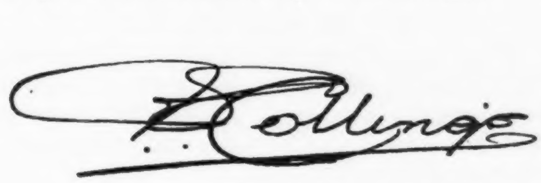
IT has long been recognized practice, especially in the eastern and midwestern states, to design the furnaces of stationary boilers for the particular class of coal which it is the intention to burn, and since the advent of the water-cooled furnace, this tendency has become more pronounced. With the further addition of the wet-bottom or slag-tap system of ash removal, it has become still more desirable that the furnace be designed for the specific fuel to be used; first, so that the maintained temperature be high enough to insure complete and rapid combustion; second, so that as much of the ash as possible may be thrown down in a state of fusion before reaching the convection surface; and, third, so that the temperature of the gases may be below the fusion point of the ash before they enter the first bank of convection tubes.

The availability of other forms of fuel in some locations raises the question whether the furnace should be designed to serve with either coal or gas, or with oil or gas, or, possibly, with all three of these fuels, although it is in only a very few parts of the country that all three are available and comparable in cost.

With regard to coal and gas, the conditions described above require that the furnace be designed primarily for burning the available grade of coal, as it has already been demonstrated that either coke-oven gas or natural gas can be burned successfully in such a furnace. In addition it has been proved that a mixture of coke-oven gas and pulverized coal can be burned successfully in a furnace designed primarily for pulverized coal. Blast-furnace gas and coke-breeze are also being burned fairly successfully in a common furnace in certain of the steel mill power houses, but in this case also it is desirable to design the furnace with a view to the peculiarities of coke-breeze, the gas being given secondary consideration. The low heat value of blast-furnace gas, however, and consequently the very large volume which must be handled for a given heat output, presents a problem which involves the free areas and heat transfer rates throughout the boiler unit, so that any considerable use of this fuel requires a study of conditions which would not occur in the case of either natural gas, coke-oven gas, or oil.

In the southwestern states, where natural gas is the primary fuel, it has always been found desirable to provide oil-burning equipment also, on account of the somewhat wide and frequent variations in the quality and pressure of the gas. No difficulty has been experienced in burning these two fuels in the same furnace which is usually of the air-cooled refractory type of construction.

It has become evident, however, that the successful burning of pulverized coal, oil, or gas, or any combination of these fuels, is, first of all, dependent upon the design and location of the burners, which must be designed for the proper velocities, for proper mixture of the fuel with the air for its combustion, and for adequate protection from radiant heat when any one burner is out of service. If this problem is given careful consideration and the mechanical details thoroughly worked out, it is not too much to say that any furnace which will burn coal successfully will burn coke-oven gas or natural gas without difficulty or detriment.



Sargent & Lundy, Chicago, Ill.

# EDITORIAL

## Good Design—an Incentive to Good Operation

RADICAL changes have taken place during recent years in the design of steam power plants and their equipment. With the improvement in economy, the increase in size and the greater reliability of operation, there have come striking changes in the appearance of both the buildings themselves and the apparatus which they house.

There is no rational relationship between ugliness and efficiency.

Our modern steam plants reflect an appreciation of architectural beauty. Steel stacks are painted in dull aluminum or battleship gray to blend into the surrounding landscape and to avoid sharp contrasts with the neutral tones of the sky. Brick and concrete chimneys are designed to harmonize with the architectural scheme of the main structure.

Inside the plant, the uncouth attempts of the past to dress up the equipment have given way to a dignified simplicity of design. Modern manufacturers have scrapped the patterns for the huge "spread eagles" of burnished brass and the ridiculous, elaborately decorated cast-iron columns that once graced the boiler fronts.

Aisles have been widened to provide adequate working space, giant windows ofttimes reaching to the roof flood the plant with light, and, surfaced concrete floors and tiled or painted walls permit a degree of cleanliness, unknown and, in fact, impossible under the conditions of the past.

These improvements in the design of plant and equipment form the basis for the higher standards of plant housekeeping which characterize present day operation. They provide an incentive for safer and more orderly plant routine—factors which are sometimes difficult to evaluate but which, nevertheless, are eventually translated into reduced operating costs.

## Pulverized Fuel Drops The Load

COUNTLESS examples have been cited of the flexibility of various firing methods in assuming sudden load demands. At times it is equally important that the steam generating system be able to drop the load quickly.

Here is an example in point.

Not so long ago, all the breakers in a large central station "kicked out" practically simultaneously due to transmission line trouble. The full line peak load dropped instantly to practically zero—merely the house load.

The boilers, pulverized fuel fired, had been operating between 350 and 400 per cent of rating when the break occurred.

The operator pushed one emergency button. Every mill, every feeder stopped at once and in less than five seconds not a particle of burning fuel remained in the furnaces and the last of the long plumes of combustion gases had been whisked through the boilers and up the stacks.

The flowmeter pen drew a sharp vertical line, from around 400 per cent to practically no rating.

A few minutes later the line load was re-established and a simple manipulation of push buttons brought the boilers back on the line. Another vertical line appeared on the flow chart—indicating peak rating.

The ability of pulverized fuel firing to assume sudden load demands is generally recognized. In emergencies it is just as flexible in "getting out from under."

## The Challenge of Youth

ANOTHER June is at hand and scores of technical schools throughout the country will pour their quotas of embryo engineers into a market which, at the present time, is definitely beyond the saturation point.

These engineering graduates offer a knowledge of fundamentals and of the history and present status of engineering development. They seek the opportunity to apply those fundamentals to new problems and thus contribute toward engineering progress and the making of engineering history.

Though lacking the intuitive judgment which comes alone from long experience, these young engineers are, on the average, better equipped than were their predecessors.

In the past, technical training has invariably hastened individual advancement. Today, with the increasing complexity of all branches of engineering, a sound technical background is imperative in merely keeping pace.

Technical schools now provide a happy admixture of theory and practicality. In classrooms and laboratories, mathematics, physics, chemistry and metallurgy have been put to work in definite applications comparable with the problems which the student will encounter after he has passed the threshold of his profession.

These young men bring to the market place, a sound grounding in fundamentals, an appreciation of practical application and the enthusiasm of youth. Such youth will be served and if there is an over supply of engineering talent, the adjustment will probably take place by the eventual crowding out of the less capable and more poorly equipped incumbents of the old school who have failed to keep step with the ever quickening pace of engineering advancement.

# The Physical Characteristics of Natural Draft Chimneys*

PART TWO

By J. G. MINGLE

Indianapolis, Ind.

**In the second and concluding part of his article, Mr. Mingle describes the construction of the several types of steel and reinforced concrete chimneys, discusses their development and fields of application and lists the advantages and disadvantages of each type . . . The selection of the most suitable type of chimney for a particular plant is an important problem involving a number of factors. Mr. Mingle's comprehensive discussion of these factors will serve as a valuable guide to those confronted with this problem.**

HAVING considered the characteristics and construction of brick chimneys of both the common brick and perforated radial brick types, we shall now discuss the several types of steel and reinforced concrete chimneys.

*Steel Chimneys*

There are two general types of steel chimneys according to the type of construction, viz: (1) guyed steel chimneys, or stacks and (2) self-supporting, or self-sustaining, steel chimneys.

Guyed steel chimneys, or guyed steel stacks as they are commonly called, are the cheapest type of chimney which can be built and are also the least durable. They are used on small units, or single boilers, and in installations where permanency is of secondary importance. Chimneys of this type are built of relatively thin steel plate of from No. 10 to 5/16 in. material, usually assembled in two or three pieces in the shop, shipped or carted to the destination, and erected in place by means of a gin-pole. They are usually set directly over the smoke up-take and are anchored in a vertical position by means of from one to three groups of guys of four wires each. Guyed steel stacks are seldom built to a height greater than 125 ft., a fair average height being about 100 ft. The diameter usually ranges between 30 and 60 in. Occasionally one is lined with a refractory material for a portion of its height but as a general rule no lining whatsoever is used.

Guyed steel stacks are used principally in temporary installations, in plants where permanency is of secondary consideration, on small units such as those of 150 hp. and less, when a large chimney is not required, where the multiple chimney system is used, where the character of the soil is such that it will not support a self-supporting chimney except at great expense, and in other installations where the expense will not warrant the use of a chimney of any other type.

The chief advantages of guyed steel stacks are: they can be easily assembled and erected and just as easily taken down and removed; they can be erected under almost any adverse conditions; their cost is relatively low. The chief disadvantages are: their relatively short life (usually from 5 to 7 yr.); they cannot be built to a great height; the guys around the plant are a nuisance; sway due to impossibility of tight guying affects boiler and other parts of the plant; constant danger of damage to person and property due to wind blowing off the part above the anchor ring after the structure has been in use for some time; high upkeep expense and maintenance due to necessity of periodical painting and repairs.

Self-supporting steel chimneys, or self-sustaining as they are sometimes called, are used quite extensively in installations where it is impossible or inexpedient to build of brick or concrete. During late years their use has been confined largely to central station plants, and other plants of a similar nature, where it is necessary or expedient for one reason or another to erect the chimney on top of the boiler house structure. Chimneys of this type are also used quite extensively in high temperature installations. While steel chimneys of this type may be more or less of a semi-permanent nature, yet their use is by no means uncommon, and, where properly applied and maintained, their life may be extended to a fairly long number of years. Self-supporting steel chimneys are constructed of steel plate rolled to the proper radius and punched for rivets. This work is done in the shop. The plates, which are usually about 5 ft. in height and two in number to a section, are then shipped to the site of erection and riveted one section to another both vertically and circumferentially in the process of erection. The thickness of the plate usually averages from 3/16 to 1/4 in. at the top and increases by multiples of 1/16 in. per

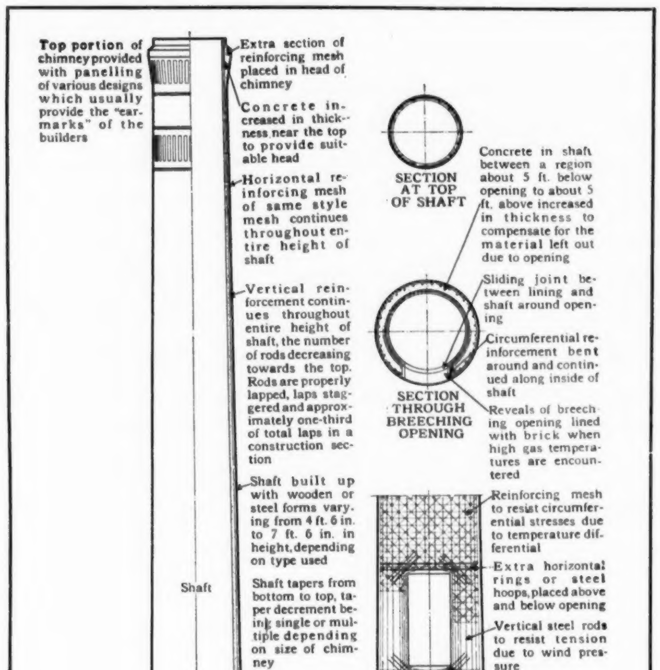
40 ft., or so, downwards. Four schemes are used in lapping the sections: bottom of upper section lapped over top of lower section, usually called the "shingle" lap; top of lower section lapped over bottom of upper section; top and bottom of one section lapped alternately over and under section above and below; and butt strap lap. The shingle lap is perhaps the best due to the fact that moisture cannot seep into the ring seam and run down the inside of the shell. The vertical edges simply lap one over the other. The lower approximately one-sixth of the height is "flared" outward in the shape of a bell mouth in order to provide a larger circumference at the bottom than would otherwise be possible so that the anchor bolts which connect the shaft to the footing will have a greater radius of gyration, and also to compensate for the material left out due to the breeching opening.

Chimneys of this type are almost invariably lined with a refractory material of fire brick, or perforated radial chimney brick. The purpose of the lining in a steel chimney is to reduce radiation to a minimum and also to protect the inside of the steel shell from the injurious effects and the corrosive action of the chimney gases. The lining may be built up independent of the steel shell, or laid on horizontal angles riveted to the horizontal joints forming ledges from 20 to 30 ft. apart. With the latter arrangement, any section of the lining may be removed and replaced without interfering with the rest. It is not good practice to leave an air-space between the lining and the steel shell due to the fact that gases may percolate through the joints of the lining and condense in the air-space thereby creating sulphurous acid which readily and vigorously attacks the metal. This air-space should be filled with a lean grout.

An excellent material for lining steel chimneys is CE-CO Stack and Flue Lining. This material which has an asbestos base adheres directly to the inside of the metal shell, leaving no joint, crevice or air-space behind the lining into which the injurious acids and acid gases can collect. It insulates the metal from the highly corrosive conditions and, like typical refractory linings, reduces radiation to a minimum. The material forms a dense, tough, acid, water and heat resisting barrier. Incidentally it also resists the erosive action of cinders and dust particles. Its cost is no greater than that of typical refractory linings and, properly applied, it will not crumble or disintegrate with age or rough usage.

The footing of a self-supporting steel chimney is made of sufficient area to provide proper stability against overturn and excessive toe soil pressure, and of sufficient thickness to properly accommodate the full length of the anchor bolts which anchor the steel shell to the foundation. These anchor bolts are bolted to the base plate which is riveted to the bottom section of the steel shell. In case the chimney is built on top of the power house building, the shell is then bolted to the main structural members.

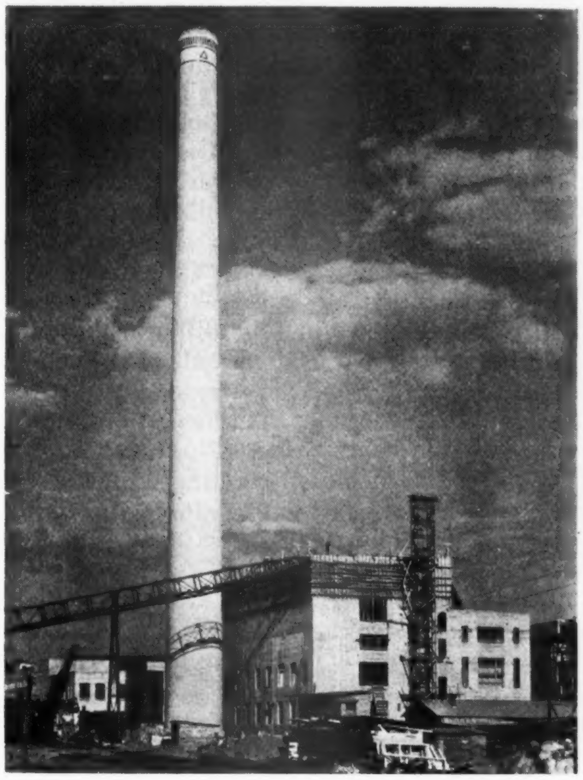
The chief advantages of self-supporting steel chimneys are: relatively light weight (even when the lining is considered) thereby effecting considerable saving over other types when erected on top of power house building due to the fact that less heavy structural members will be required to support the superincumbent weight; unlike brick and concrete are not affected by extremely high chimney gas temperatures; freedom from possibility of cracking; ease of erection and dismantling; and, as a general rule, relatively less cost when compared with the other types of chimneys. The chief disadvantages are: upkeep expense due to painting and repairs; relatively short life; and disturbing effect of swaying due to non-rigidity of steel shell.




**Typical Reinforced Concrete Chimney**

*Reinforced Concrete Chimneys*

The reinforced concrete chimney is the most recently developed type of chimney construction. Chimneys of this type combine great structural strength with wide adaptibility and their use is constantly increasing. Due to the character and condition of the materials used, steel and brick chimneys can be erected with relative ease and the hazard of the human element is not prominent. In the construction of reinforced concrete chimneys, however, forms of a rather complicated nature are used and workmanship of no mean ability is required; as a result the hazards of erection are increased. When properly constructed, chimneys of this type compare favorably with any others.



**300 ft. by 14 ft. dia. reinforced concrete chimney.**

The first reinforced concrete chimneys erected were built in the late nineties and were more or less of an experiment. The early builders were, of course, rather inexperienced in this type of construction and, as is the case with any pioneer form of building, some failures resulted. These failures were due not to any inherent defect in the structures themselves but to the uncertain human element in their construction, although in many cases the failures were unjustly attributed to the former. As the builders became more experienced and the design and form were improved, the causes of the early failures were gradually overcome and permanent structures invariably resulted.

Compared with the present day structures, the first reinforced concrete chimneys built were indeed crude looking affairs although the looks in no case detracted from their stability and usefulness. These early chimneys were built cylindrical in shape from bottom to top. Due to the fact that the lower one-third of the chimney was lined, an offset was built in the outer wall at the top of the lining in order that the inside diameter of the part of the shaft above the lining would be the same as the diameter of the lining. This scheme, of course, resulted in a saving of materials in the upper two-thirds of the shaft. The reinforcement consisted of numbers of small T-rods properly spaced and imbedded in the concrete both vertically and circumferentially. The cement and aggregates were thoroughly mixed and then tamped in place in a dry state after which the mixture was thoroughly wetted. While no brief can be held, in the light of modern practice, for this method of construction, yet it may be said that several hundred chimneys were erected after this fashion, some of them to heights of 350 ft. and greater, and their material condition, after years of constant use, was better than could ever have been expected.

The modern reinforced concrete chimney came into being when the tapering shaft was designed, that is, when the shaft was built in the general form of a truncated cone, and tapered forms were used. The use of tapered forms greatly increased the difficulties and cost of construction but this increase was offset somewhat by the saving in materials, particularly in the reinforcement, over the cylindrical type. The tapering type chimney is a much better looking structure, is more stable and has the materials placed to better advantage.

As may be assumed from its name, the walls of a tapering reinforced concrete chimney taper from the bottom to the top, or, in other words, the outside diameter decreases from bottom to the top. With small sizes the batter of the walls is constant throughout but in the larger sizes, the batter varies and gradually decreases by section as the top is approached. The wall thickness of the shaft also decreases towards the top. The decrement of the outside diameter and the wall thickness varies according to the judgment of the designer but averages about 5/16 in. per ft. for the former and about 1/10 in. per ft. for the latter. The wall thickness at the top of the chimney is usually arbitrarily assumed at 4 in. for diameters up to about 8 ft., 5 in. for diameters between 8 and 15 ft. and 6 in. for diameters greater than 15 ft.

There are two systems of steel reinforcement in a reinforced concrete chimney, the vertical and the circumferential. The vertical reinforcement which resists the tension due to wind pressure and other forces consists of vertical steel rods, round, square or deformed, the size of the rods and their spacing depending upon the amount of tension to be resisted. The rods are properly lapped with the laps arranged so that all do not occur at any section. The circumferential reinforcement which resists the diagonal tension and also the circumferential stresses due to temperature changes usually consists of small size steel rods or a patented type of reinforcing mesh. The reinforcement not only resists the internal stresses but also ties the complete mass together thereby producing practically a

monolithic structure. All reinforcement is placed about 2 in. from the outside surface of the shaft and both systems are tied together.

Due to the fact that reinforced concrete is inherently not a typical refractory material for high temperatures, in the strict sense of the word, it is necessary to line chimneys of this type with a material that has known refractory qualities. The materials used for lining purposes are common brick, radial brick and fire brick, depending upon the degree of temperature encountered in the gases. For temperatures up to 500 to 600 deg. fahr., common brick or radial brick are usually used although it should be stated that reinforced concrete has been used to some extent with good results. For temperatures between 600 and 1200 to 1500 deg. fahr., radial brick and fire brick are used for lining purposes, and for temperatures above 1500 deg. fahr., first grade fire brick is used exclusively. For comparatively low temperatures, the lining material is usually laid up in common cement-lime-sand mortar. For high temperatures, the lining is laid up in fire clay. When strong acid and acid gases are encountered, glazed radial brick is used for lining, being laid up in a cement-sand-fire clay mortar.

The height to which the lining is built also depends upon the degree of temperature of the gases. For chimney gas temperatures up to 500 to 600 deg. fahr., the lining usually starts at the bottom of the shaft and extends about 20 ft. above the top of the breeching opening. For temperatures between 600 and 1200 to 1500 deg. fahr., the lining is built up to the constriction level of the chimney and for temperatures greater than 1500 deg. fahr., the chimney is lined throughout its entire height.

The thickness of the lining depends upon the height to which it is built and to some extent upon the degree of temperature encountered. For ordinary temperatures, the lining is usually 4 in. thick. For high temperatures, it is 9 to 13-1/2 in. in thickness and is built up independent of the shaft. In this case, when fire brick is used, the lower half of the lining is made 9 in. thick and the upper half, 4¼ in. When radial brick is used, the lining is usually divided up into sections approximately 40 ft. in height, the top section being 4 in. thick and the thickness increasing about 1½ in. for each section downwards. Oftentimes when the lining extends throughout the entire height, it is divided up into sections and laid on corbels built out from the inside of the shaft, the thickness usually being 4 in.

The breeching opening of a reinforced concrete chimney demands special attention due to the fact that it not only removes concrete from the wall thereby increasing the stresses but also is located in the region of the hottest gases. For a distance of approximately 5 ft. both above and below the opening, the wall is increased in thickness to the extent that there is no actual reduction in the area whatsoever. The metal rods extending towards the opening from both the top and the bottom are bent around and to the sides so that no rods are left out. Likewise the circumferential reinforcement is bent around and continued along the inside walls of the shaft. Two or three extra rods in the form of rings are placed directly above and below the opening. "Haunch" rods, that is rods outside of the corners and perpendicular to the diagonals of the opening are also provided. The purpose of the extra reinforcement is to preclude any possibility of serious cracks developing and opening up in this region, the weakest of the entire chimney.

The footing of a reinforced concrete chimney is usually a pad of concrete of sufficient thickness to resist the vertical shear and of sufficient spread in the form of an octagon section to preclude any tension tendency between the soil and concrete at the windward toe as well as an excessive soil, or toe, pressure at the leeward toe. The tension in the concrete in the footing is resisted by a network of steel rods extending in four different directions and parellel to the various diagonals of the octagon. The reinforcement is placed about 4 in. up from the bottom of the footing. At times, it is necessary to provide some reinforcement in the top of the footing to resist a negative bending moment. The vertical rods of the shaft extend down through the footing and are then bent outward and anchored to the footing reinforcement.

Reinforced concrete chimneys are constructed by means of wooden or metal forms supported from a removable staging which is built in advance of the concrete and on the inside of the shaft. The staging is supported on top of a scaffolding which starts on top of the footing. The outside forms are guided by radial rods which maintain the circular section while the inside forms are kept in position by means of braces behind and spacers between them and the outside forms. The outside forms are usually about 7 ft. 6 in. in height and one such section is poured at a time. The material is hauled to the staging from the inside, up through the scaffolding. After each section has been poured and has set sufficiently, the forms are raised and set in place for the next. The horizontal construction joints are then rubbed with an abrasive and made as indistinct as possible.

The concrete in the shaft is usually a 1:2:4 and in the foundation, a 1:3:6 mix.

The chief advantages of reinforced concrete chimneys are: great relative strength and stability in comparison with amount of materials used; lighter in weight than brick chimneys; require thinner footing than brick or steel; built of materials naturally adapted to resist stresses encountered, that is, concrete to resist compressive stresses and steel to resist tensile stresses; admirably well adapted to resist the shock and stresses due to earthquakes; relatively little air infiltration due to small number of construction joints; relatively cheap first cost for the taller and larger sizes; practically no maintenance required; and practically indefinite life due to permanence of materials.

The chief disadvantages of reinforced concrete chimneys are: not generally adapted by nature of materials for high temperature purposes due to the

(*Continued on page 37*)

# Performance of a Pulverized-Coal-Fired Boiler

## Using the Unit System and Tangential Firing*

By

JOHN J. GROB

and

JOSEPH GERSHBERG

The United Electric Light & Power Co.

New York

**This paper presents the detailed results of a series of tests conducted on Boiler No. 81 at the Hell Gate Station of the United Electric Light & Power Company, New York. These tests are of particular interest and value because of the nature of the results, the completeness of the data secured, and because the unit tested reflects the most modern practice in pulverized fuel firing and furnace design.**

•

PARALLELING the development of the bin and the unit systems of pulverized coal firing, various types of burners have been devised for use with either system. The aim of this paper is to present results of tests on a boiler combining the unit system and tangential firing.

The test which comprises the subject matter of this paper was conducted on boiler No. 81 at the Hell Gate Station of the United Electric Light & Power Co. This is one of three tangentially fired boilers which were installed in the existing eighth row boiler space at Hell Gate to provide part of the additional steam requirements entailed by adding two 160,000 kw. turbo-alternator units to the station. The general plant layout is shown in Fig. 1.

Due to the limited confines of the existing site and building columns it was planned to design these boilers for the maximum economic space capacity. The unit system of pulverized coal firing permitted a workable layout for the capacities desired.

Descriptive data and ratios are given in Table I.

Referring to the cross-sectional elevation, Fig. 2, the locations of the principal items of equipment with respect to the furnace are clearly depicted. Coal is weighed by means of two automatic recording scales and transported by either one of two spiral conveyors to the one hundred ton boiler bunker located above the unit mills. The coal is fed to four impact type unit mills each having a capacity of 12,500 lb. of coal per hour.

A primary supply of preheated air passes to each mill from the forced draft duct and the resultant mixture of primary air and ground coal is delivered to one of four corner burners. Preheated secondary air passes through slots in the burner above and below the primary air and coal mixture. This results in jets of coal and air from the four corner burners which impinge upon one another in a horizontal plane tangentially to an imaginary circle and thus create considerable turbulence in the furnace.

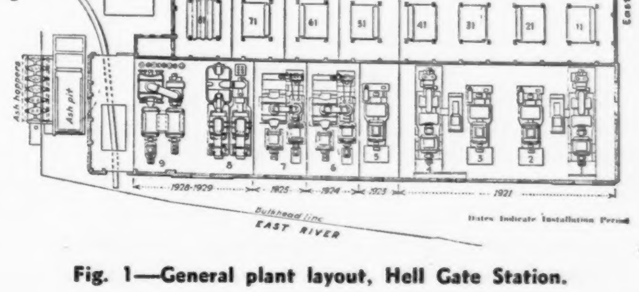


Fig. 1—General plant layout, Hell Gate Station.

The gases thereby tend to fill the furnace space

* Presented before the Power Division, A.S.M.E., New York, May 13, 1931.

and utilize most of the furnace volume, also tending to increase the transmission of heat by radiation to the water cooled surfaces.

The furnaces are completely surrounded by water walls and, in the case of boiler 81, a water screen and an inclined dry bottom ash hopper are provided.

The boilers are provided with three drums connected by downcomers to a common manifold supplying the water wall headers. The returns from the boiler uptake enter the drum located at one end, the returns from the water walls enter the one located at the opposite end while the middle drum serves as the steam offtake. They are further interconnected by steam and water loops.

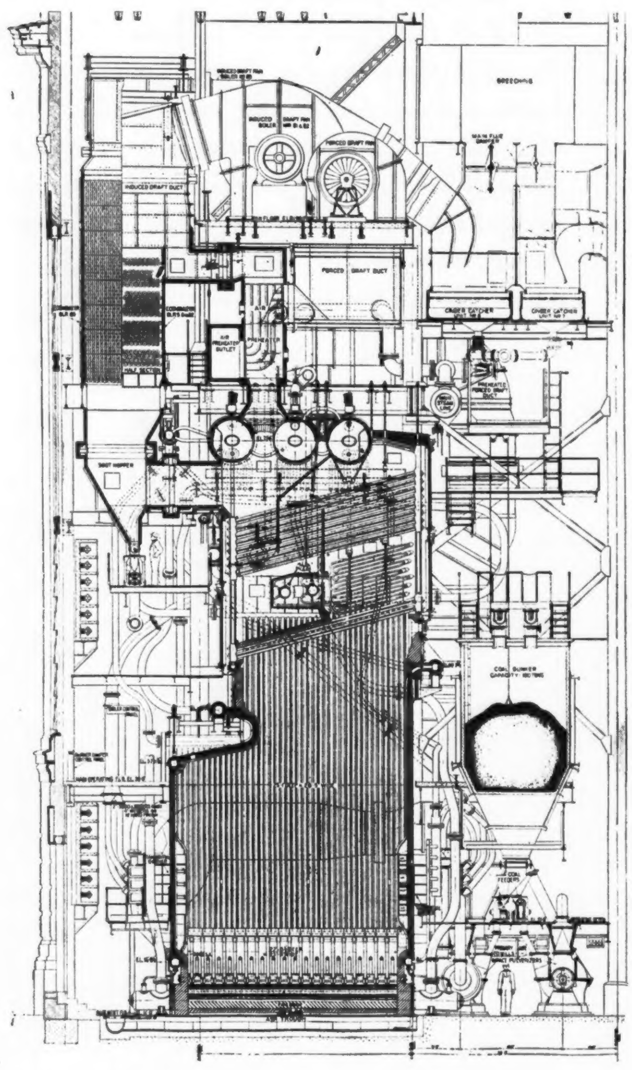


Fig. 2—Cross sectional elevation of 1928 extension to boiler plant.

Both economizers and air preheaters are utilized, the novel feature being a parallel arrangement rather than the usual series arrangement. This was dictated partly by structural limitations, and partly because of several advantageous operating features. No raw coal dryers are used other than mill drying with primary air. By dampering the gas at the air heater it is possible to adjust the tempering air to maintain mill capacity with wet coal. Normally the dampers are set to maintain equal flue gas temperatures at air heater and economizer outlets unless a coal is used with poor ignition characteristics requiring additional tempering.

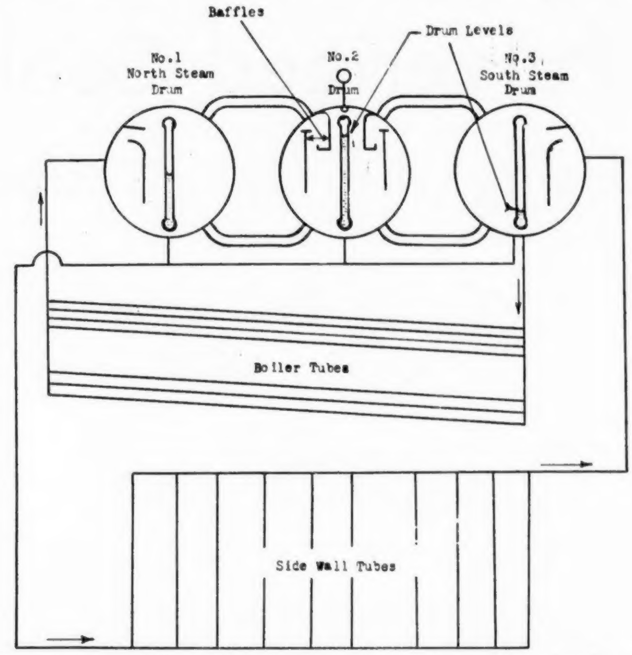



Fig. 3—Circulation diagram showing original water levels at low ratings.

The fans, driven by three-speed induction motors are provided with movable inlet vanes for draft regulation.

It had been anticipated that rapid water circulation would result from the large amount of water wall surface together with the type of pulverized fuel firing. To accommodate the swelling of the boiler contents with increased rating and to insure adequate surge capacity three drums were provided. The feed water is supplied to either one or

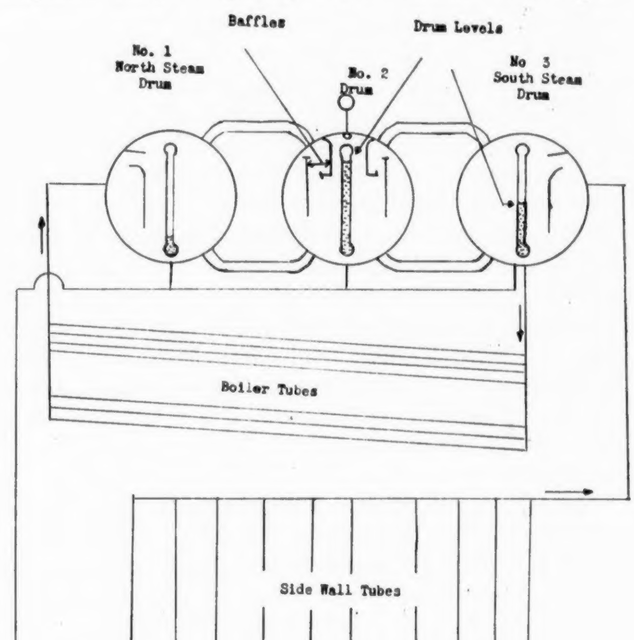



Fig. 4—Circulation diagram showing original water levels at high ratings.

both of the end drums and in normal operation the water level in the center drum is several inches lower than the end drums which gives a dry drum

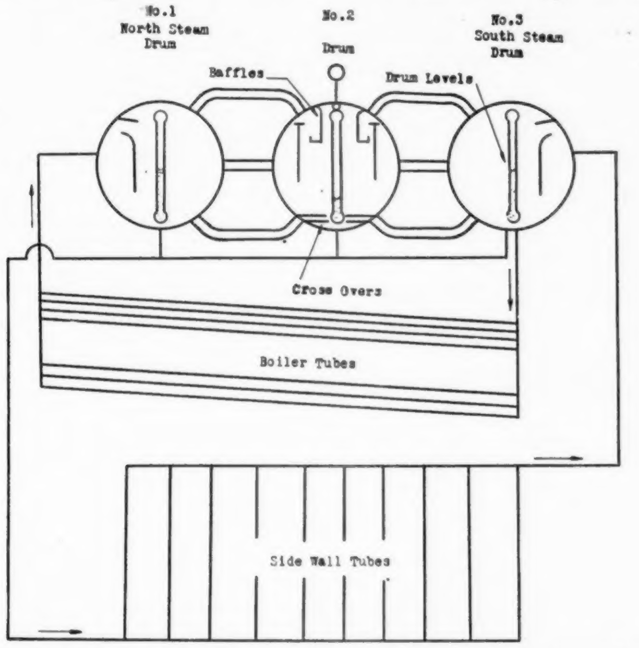



**Fig. 5—Circulation diagram showing improvement in water level after changes in drum inter-connections.**

effect with the resultant low amount of carryover moisture to the superheater.

This desirable water level feature was not obtained at the start of operation but some rather interesting unbalanced levels with occasional slugs of water were encountered. Fig. 3 indicates the levels experienced with low rating operation, No. 3 drum having a very low water level, No. 2 drum

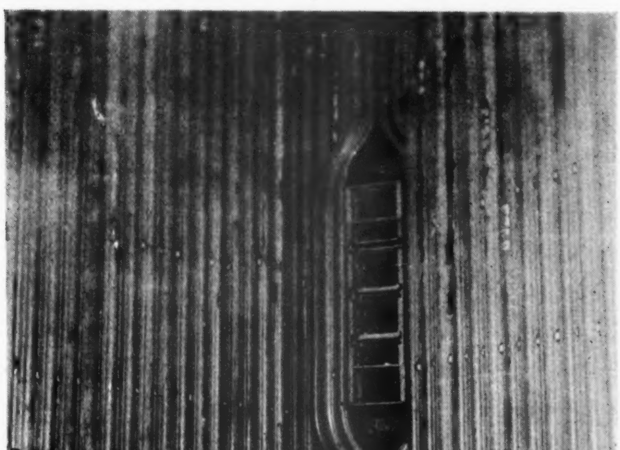


**Fig. 6—Interior of furnace of No. 81 boiler showing arrangement of burners for corner firing.**

having a very high water level, and No. 1 drum having a level in between the other two. With high rating operation the levels in No. 1 and No. 3 drums were reversed as shown in Fig. 4.

The water levels were unstable enough to cause occasional slugs of water to pass over into the superheater unless the water feed was closely controlled by hand.

It was apparent that varying rates of circulation created pressure inequalities among the drums, the center drum being low with respect to the end drums due to its steam offtake.

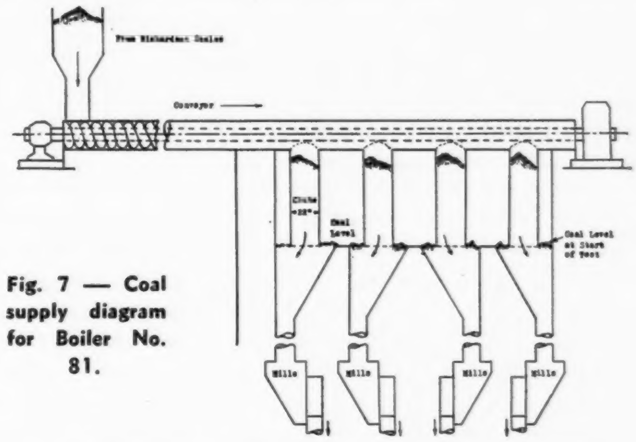



**Fig. 7 — Coal supply diagram for Boiler No. 81.**

A manometer, differentially connected among the drums, using carbon tetrachloride as the measuring fluid established pressure differences be-

*(Continued on page 26)*

## TABLE I

DESCRIPTION OF EQUIPMENT

BOILER NO. 81 HELL GATE STATION

Maker and type of boiler: Springfield, cross drum water tube.
Maker and type of superheater: Superheater Company, Elesco, bent tube, convection.
Maker and type of economizer: Foster Wheeler Company, Foster type, single pass.
Maker and type of air preheater: Combustion Engineering Co., plate.
Maker and type of fuel burning equipment: Combustion Engineering Corp., pulverizing.
Boiler heating surface: 23800 sq. ft. (including 3800 sq. ft. of water wall heating surface).
Superheater surface: 4800 sq. ft.
Economizer surface: 26136 sq. ft.
Air preheater surface: 11840 sq. ft.
Fuel: Pocahontas.
Furnace:
Dimensions: Plan 26 ft. 5 in. by 25 ft. 1 in.
Volume: 18800 cu. ft. Ratio furnace volume to boiler heating surface: 0.79.
Wall construction: Combustion Engineering Corp., fin-tube, water cooled walls insulated with 1⅞ in. Silocel, 4 in. Webber's No. 48 plaster, finished with ½ in. hard cement.
Induced Draft Fan: (1) Sturtevant. Capacity 275,000 cu. ft. per min., 14 in. static pressure. Westinghouse motor drive, 870; 690; 435 r.p.m.; 2,300 volt; 1,200 H.P.
Forced Draft Fan: (1) Sturtevant. Capacity 155,000 cu. ft. per min., 10 in. static pressure. Westinghouse motor drive, 870; 690; 435 r.p.m.; 2,300 volt; 400 H.P.
Gas Washer Equipment: Murray Cinder Catcher, spray capacity 300 g.p.m., head 50 lb. per sq. in. at sprays.
Coal handling equipment: (1) 400 ton receiving bunker:
(2) Automatic recording scales, Richardson Scale Company.
(2) Conveyors: Magnetic steel apron feeder, Link Belt Company; capacity 50 tons per hour each.
(1) Bunker delivering to unit mills, capacity 100 tons.
Combustion equipment: Combustion Engineering Corp., unit system.
Drier: type, mill-drying.
Mills: (4) Raymond Impact No. 82; capacity 12,500 lb. per hr. each.
(4) Burners, tangential, three elements per burner, one burner per mill.
Air supply: Primary 15 per cent of total introduced at mill at 280 deg. fahr.; primary air fan integral with mill.
Secondary air 85 percent of total introduced at burner at 280 deg. fahr.
Ash disposal (furnace) hydraulic.
Control: Smoot Engineering Company.
Meter: Bailey steam-flow air-flow, type D 25 F. Includes temperature recorder: Gas boiler outlet and economizer outlet.
Forced and induced draft fan: Ammeters for slow, medium, and high speed on each.
Vane openings: Selsyn indicators for both induced and forced draft ducts.
Ellison pointer draft gages: (4) burner pressures; induced draft fan outlet; boiler outlet.
Temperature indicator: Engelhard multipoint. Gas at boiler outlet, economizer outlet, air preheater outlet, induced draft fan outlet.
Air temperatures: Air preheater inlet and outlet.

# TABLE II—DATA OF TESTS

## HOURLY QUANTITIES

| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| Duration of run, hr. | 12 | 24 | 3 | 3 | 3 | 3 | 24 | 24 | 24 | 3 | 3 | 3 | 20 |
| No. of burners | 3* | 3* | 4 | 4 | 4 | 4 | 3* | 4 | 4 | 4 | 4 | 4 | 4 |
| Fuel as fired per hr., lb. | 12330 | 18875 | ← | 20920 | | → | 21330 | 20910 | 28200 | ← | 31800 | → | 32140 |
| Dry fuel per hr., lb. | 11710 | 18065 | ← | 19720 | | → | 20430 | 19840 | 27300 | ← | 30070 | → | 30690 |
| Fuel as fired/burner/ hr., lb. | 4110 | 6290 | ← | 5230 | | → | 7110 | 5230 | 7050 | ← | 7950 | → | 8040 |
| Dry fuel/burner/hr., lb. | 3900 | 6020 | ← | 4930 | | → | 6810 | 4960 | 6820 | ← | 7520 | → | 7670 |
| Refuse per hr., lb. | 915 | 1679 | 1543 | 1500 | 1513 | 1467 | 1595 | 1308 | 2720 | 2360 | 2040 | 2420 | 2425 |
| Actual water per hr., lb. | 131400 | 192900 | ← | 213500 | | → | 215200 | 216500 | 281200 | ← | 318600 | → | 326000 |
| Factor of evaporation | 1.133 | 1.137 | 1.153 | 1.142 | 1.133 | 1.118 | 1.135 | 1.137 | 1.135 | 1.131 | 1.128 | 1.135 | 1.133 |
| Equivalent evap. per hr., lb. | 149000 | 219300 | 246200 | 243900 | 241900 | 239000 | 244400 | 246000 | 319000 | 361000 | 359400 | 362000 | 369000 |
| Units of evaporation U.E. | 144600 | 213000 | 239000 | 237000 | 234800 | 232000 | 237000 | 238600 | 310000 | 350000 | 348500 | 351000 | 358000 |
| (a) Boiler hp.—Average hp. | 4320 | 6360 | 7130 | 7050 | 7010 | 6930 | 7080 | 7130 | 9250 | 10470 | 10420 | 10500 | 10700 |
| Heat liberated by fuel per cu. ft. of combustion space per hr. B.t.u./cu. ft./hr. | 9080 | 13700 | 15260 | 15280 | 15290 | 15300 | 15740 | 15500 | 20600 | 23240 | 23500 | 23200 | 23600 |

* Note—S. W. burner was shut down during these tests.

## HEAT BALANCE

| Run No. | 9 | | 5 | | 7b | | 4 | |
|---|---|---|---|---|---|---|---|---|
| | B.t.u. | % | B.t.u. | % | B.t.u. | % | B.t.u. | % |
| **At Furnace Outlet** | | | | | | | | |
| Heat per pound of coal (dry) | ..... | ..... | 14544 | 98.6 | 14669 | 97.5 | 14752 | 98.2 |
| Heat supplied by preheated air per pound of coal | ..... | ..... | 203 | 1.4 | 371 | 2.5 | 270 | 1.8 |
| Total heat supplied | ..... | ..... | 14747 | 100 | 15040 | 100 | 15022 | 100 |
| Heat loss due to moisture in coal | ..... | ..... | 77 | 0.5 | 105 | 0.7 | 76 | 0.5 |
| Heat loss due to combustion of hydrogen | ..... | ..... | 732 | 5.0 | 749 | 5.0 | 728 | 4.8 |
| Heat loss due to moisture in air | ..... | ..... | 116 | 0.8 | 138 | 0.9 | 168 | 1.1 |
| Heat remaining in dry chimney gases | ..... | ..... | 5960 | 40.4 | 6204 | 41.3 | 5766 | 38.4 |
| Heat loss due to combustible in refuse | ..... | ..... | 281 | 1.9 | 94 | 0.6 | 257 | 1.7 |
| Heat absorbed by furnace, and loss from radiation and unaccounted for | ..... | ..... | 7581 | 51.4 | 7750 | 51.5 | 8027 | 53.5 |
| **At Boiler Outlet** | | | | | | | | |
| Heat value per pound of coal (dry) | 14768 | 100 | 14544 | 98.6 | 14669 | 97.5 | 14752 | 98.2 |
| Heat supplied by preheated air per pound of coal | ..... | ..... | 203 | 1.4 | 371 | 2.5 | 270 | 1.8 |
| Total heat supplied | 14768 | 100 | 14747 | 100 | 15040 | 100 | 15022 | 100 |
| Heat absorbed by water and steam in boiler and superheater | 12340 | 83.6 | 11780 | 79.9 | 11960 | 79.5 | 11620 | 77.4 |
| Heat loss due to moisture in coal | 62 | 0.4 | 54 | 0.4 | 73 | 0.5 | 54 | 0.4 |
| Heat loss due to combustion of hydrogen | 503 | 3.4 | 518 | 3.5 | 520 | 3.5 | 517 | 3.4 |
| Heat loss due to moisture in air | 17 | 0.1 | 32 | 0.2 | 39 | 0.3 | 49 | 0.3 |
| Heat loss due to dry chimney gases | 1585 | 10.7 | 1679 | 11.4 | 1884 | 12.5 | 1748 | 11.6 |
| Heat loss due to combustible in refuse | 193 | 1.3 | 281 | 1.9 | 94 | 0.6 | 257 | 1.7 |
| Unaccounted for loss | 68 | 0.5 | 403 | 2.7 | 470 | 3.1 | 777 | 5.2 |

## HEAT BALANCE (Continued)

| Run No. | 3 | | 1 | | 6b | | 2 | |
|---|---|---|---|---|---|---|---|---|
| | B.t.u. | % | B.t.u. | % | B.t.u. | % | B.t.u. | % |
| **At Furnace Outlet** | | | | | | | | |
| Heat per pound of coal (dry) | 14826 | 97.9 | 14433 | 98.1 | 14812 | 98.3 | 14732 | 97.3 |
| Heat supplied by preheated air per pound of coal | 314 | 2.1 | 285 | 1.9 | 256 | 1.7 | 414 | 2.7 |
| Total heat supplied | 15140 | 100 | 14718 | 100 | 15068 | 100 | 15146 | 100 |
| Heat loss due to moisture in coal | 92 | 0.6 | 59 | 0.4 | 102 | 0.7 | 85 | 0.6 |
| Heat loss due to combustion of hydrogen | 750 | 5.0 | 725 | 4.9 | 777 | 5.2 | 750 | 5.0 |
| Heat loss due to moisture in air | 121 | 0.8 | 124 | 0.8 | 144 | 1.0 | 191 | 1.2 |
| Heat remaining in dry chimney gases | 5965 | 39.4 | 6161 | 41.9 | 6441 | 42.8 | 6465 | 42.7 |
| Heat loss due to combustible in refuse | 129 | 0.9 | 243 | 1.7 | 112 | 0.7 | 281 | 1.8 |
| Heat absorbed by furnace, and loss from radiation and unaccounted for | 8083 | 53.4 | 7406 | 50.3 | 7492 | 49.7 | 7374 | 48.7 |
| **At Boiler Outlet** | | | | | | | | |
| Heat value per pound of coal (dry) | 14826 | 97.9 | 14433 | 98.1 | 14812 | 98.3 | 14732 | 97.3 |
| Heat supplied by preheated air per pound of coal | 314 | 2.1 | 285 | 1.9 | 256 | 1.7 | 414 | 2.7 |
| Total heat supplied | 15140 | 100 | 14718 | 100 | 15068 | 100 | 15146 | 100 |
| Heat absorbed by water and steam in boiler and superheater | 12030 | 79.5 | 11330 | 77.0 | 11600 | 76.9 | 11660 | 77.0 |
| Heat loss due to moisture in coal | 65 | 0.4 | 41 | 0.3 | 72 | 0.5 | 59 | 0.4 |
| Heat loss due to combustion of hydrogen | 527 | 3.5 | 502 | 3.4 | 545 | 3.6 | 518 | 3.4 |
| Heat loss due to moisture in air | 34 | 0.2 | 35 | 0.2 | 45 | 0.3 | 54 | 0.4 |
| Heat loss due to dry chimney gases | 1708 | 11.3 | 1796 | 12.2 | 2088 | 13.9 | 1939 | 12.8 |
| Heat loss due to combustible in refuse | 129 | 0.9 | 243 | 1.7 | 112 | 0.8 | 281 | 1.9 |
| Unaccounted for loss | 647 | 4.2 | 771 | 5.2 | 606 | 4.0 | 635 | 4.1 |

## FUEL DATA

| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| **Fuel Proximate Anal.—As Fired** | | | | | | | | | | | | | |
| Volatile matter | 20.84 | 19.56 | | 20.80 | | | 20.82 | 20.98 | 20.31 | | 20.26 | | 20.30 |
| Fixed carbon | 67.98 | 69.08 | | 66.88 | | | 69.14 | 68.51 | 68.48 | | 68.58 | | 69.47 |
| Ash | 6.18 | 7.08 | | 6.58 | | | 5.80 | 5.41 | 8.03 | | 5.70 | | 5.71 |
| Moisture | 5.00 | 4.30 | | 5.74 | | | 4.24 | 5.10 | 3.18 | | 5.46 | | 4.52 |
| Heating value per lb. (fired), B.t.u. | 14030 | 13919 | | 13827 | | | 14126 | 14070 | 13974 | | 14003 | | 14066 |
| Heating value per lb. (dry), B.t.u. | 14768 | 14544 | | 14669 | | | 14752 | 14826 | 14433 | | 14812 | | 14732 |
| Fusion temperature of ash, °F. | 2270 | 2320 | | 2280 | | | 2270 | 2270 | 2300 | | 2300 | | 2290 |
| **Fuel Ultimate Anal.—Dry** | | | | | | | | | | | | | |
| Carbon | 83.37 | 83.07 | | 83.86 | | | 84.45 | 84.35 | 82.55 | | 84.35 | | 84.59 |
| Hydrogen | 4.53 | 4.55 | | 4.54 | | | 4.53 | 4.61 | 4.34 | | 4.62 | | 4.44 |
| Oxygen | 3.84 | 3.14 | | 2.77 | | | 3.16 | 3.56 | 3.05 | | 3.19 | | 3.13 |
| Nitrogen | 1.18 | 1.18 | | 1.20 | | | 1.28 | 1.18 | 1.13 | | 1.21 | | 1.21 |
| Sulphur | 0.58 | 0.68 | | 0.65 | | | 0.62 | 0.60 | 0.63 | | 0.60 | | 0.65 |
| Ash | 6.50 | 7.38 | | 6.98 | | | 6.06 | 5.70 | 8.30 | | 6.03 | | 5.98 |
| **Pulverized Coal Fineness Test** | | | | | | | | | | | | | |
| Through 100 mesh | 92 | 90 | 92 | 92 | 84 | 92 | 89 | 93 | 92 | 91 | 79 | 88 | 86 |
| Through 200 mesh | 77 | 74 | 88 | 77 | 60 | 76 | 70 | 88 | 75 | 69 | 65 | 69 | 69 |
| Through 325 mesh | 37 | 36 | 44 | 43 | 44 | 38 | 32 | 40 | 26 | 33 | 33 | 23 | 46 |

## TABLE II—DATA OF TESTS (Continued)

### GAS ANALYSIS

| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| **Boiler Outlet** | | | | | | | | | | | | | |
| Carbon-dioxide ....% | 13.0 | 13.7 | 15.8 | 13.4 | 12.8 | 11.2 | 14.1 | 14.0 | 14.0 | 15.4 | 13.9 | 12.5 | 13.9 |
| Oxygen ....% | 6.6 | 5.5 | 3.4 | 5.8 | 6.6 | 8.4 | 5.3 | 5.2 | 5.3 | 3.9 | 5.2 | 6.8 | 5.4 |
| Carbon-monoxide ....% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nitrogen ....% | 80.4 | 80.8 | 80.8 | 80.8 | 80.6 | 80.4 | 80.6 | 80.8 | 80.7 | 80.7 | 80.9 | 80.7 | 80.7 |
| **Economizer Outlet** | | | | | | | | | | | | | |
| Carbon-dioxide ....% | 10.9 | 12.6 | 14.1 | 12.3 | 11.2 | 9.6 | 12.6 | 12.4 | 12.1 | 13.3 | 12.7 | 11.5 | 12.2 |
| Oxygen ....% | 8.8 | 6.8 | 5.2 | 7.2 | 8.5 | 10.3 | 6.8 | 6.8 | 7.4 | 6.2 | 6.8 | 8.2 | 7.2 |
| Carbon-monoxide ....% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nitrogen ....% | 80.3 | 80.6 | 80.7 | 80.5 | 80.3 | 80.1 | 80.6 | 80.8 | 80.5 | 80.5 | 80.5 | 80.3 | 80.6 |
| **Air Heater Outlet** | | | | | | | | | | | | | |
| Carbon-dioxide ....% | 10.0 | 9.3 | 11.7 | 10.0 | ..... | 8.3 | 10.4 | 10.5 | 9.2 | 10.1 | 9.7 | 9.0 | 10.6 |
| Oxygen ....% | 9.6 | 10.3 | 7.9 | 9.5 | ..... | 11.7 | 9.2 | 8.9 | 10.4 | 9.6 | 10.1 | 10.8 | 9.0 |
| Carbon-monoxide ....% | 0 | 0 | 0 | 0 | ..... | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nitrogen ....% | 80.4 | 80.4 | 80.4 | 80.5 | ..... | 80.0 | 80.4 | 80.6 | 80.4 | 80.3 | 80.2 | 80.2 | 80.4 |
| **Dry Gas per lb. Fuel,** | | | | | | | | | | | | | |
| Boiler outlet ....lb. | 15.99 | 15.02 | 13.43 | 15.73 | 16.44 | 18.71 | 14.86 | 15.14 | 14.67 | 13.70 | 15.26 | 16.63 | 15.10 |
| Economizer outlet ....lb. | 18.83 | 16.25 | 14.93 | 17.06 | 18.69 | 21.68 | 16.56 | 16.98 | 16.84 | 15.70 | 16.62 | 18.00 | 17.10 |
| Air heater outlet ....lb. | 20.60 | 21.73 | 18.00 | 20.80 | ..... | 25.00 | 19.90 | 19.92 | 21.90 | 20.40 | 21.52 | 22.78 | 19.55 |
| Theoretical ....lb. | 11.52 | 11.40 | 11.64 | 11.67 | 11.67 | 11.68 | 11.60 | 11.72 | 11.31 | 11.59 | 11.72 | 11.58 | 11.57 |
| **Air Supplied per lb. Fuel,** | | | | | | | | | | | | | |
| Furnace—dry ....lb. | 15.48 | 14.51 | 12.92 | 15.22 | 15.93 | 18.19 | 14.35 | 14.62 | 14.16 | 13.19 | 14.75 | 16.13 | 14.58 |
| **Percent Excess Air Boiler—** | | | | | | | | | | | | | |
| Outlet ....% | 44.7 | 37.0 | 19.5 | 40.4 | 46.9 | 67.6 | 33.2 | 34.4 | 34.8 | 22.6 | 35.5 | 49.9 | 35.4 |

### PRESSURES AND DRAFTS

| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| Moisture in air ....lb. per lb. of air | .006 | .011 | .012 | .012 | .012 | .013 | .016 | .011 | .011 | .012 | .012 | .013 | .016 |
| Steam pressure gage, boiler....lb. per sq. in. | 278 | 288 | 288 | 289 | 290 | 287 | 287 | 288 | 292 | 303 | 303 | 300 | 300 |
| Steam pressure gage, sup't out....lb. per sq. in. | 278 | 286 | 285 | 285 | 286 | 284 | 284 | 284 | 287 | 294 | 294 | 293 | 291 |
| Water pressure gage, econ. inlet....lb. per sq. in. | 438 | 441 | 434 | 431 | 439 | 427 | 445 | 441 | 440 | 453 | 457 | 441 | 447 |
| Water pressure gage, econ. outlet....lb. per sq. in. | 419 | 401 | 384 | 379 | 391 | 383 | 395 | 395 | 356 | 338 | 366 | 340 | 332 |
| **Air Pressures** | | | | | | | | | | | | | |
| At air heater inlet....in. water | —0.12 | 1.24 | 1.40 | 1.00 | 1.68 | 1.50 | 1.43 | 1.14 | 2.26 | 4.56 | 5.39 | 6.18 | 4.61 |
| At air heater outlet....in. water | —0.12 | 1.08 | 1.20 | 0.76 | 1.29 | 1.14 | 1.17 | 0.95 | 1.90 | 3.82 | 4.52 | 5.16 | 3.60 |
| At primary air at burner....in. water | 2.9 | 3.6 | 2.0 | 3.8 | 4.0 | 3.7 | 3.7 | 2.9 | 4.5 | 5.4 | 6.0 | 5.2 | 5.7 |
| At secondary air at burner....in. water | —0.34 | 0.80 | 1.00 | 0.30 | 0.80 | 0.60 | 0.90 | 0.64 | 1.20 | 3.00 | 3.60 | 3.90 | 2.90 |
| **Draft** | | | | | | | | | | | | | |
| In furnace ....in. water | 0.43 | 0.15 | 0.24 | 0.30 | 0.24 | 0.51 | 0.15 | 0.22 | 0.38 | 0.12 | 0.13 | 0.16 | 0.22 |
| At boiler outlet ....in. water | 1.21 | 1.77 | 1.92 | 2.55 | 2.92 | 3.93 | 2.18 | 2.27 | 4.03 | 4.56 | 5.27 | 6.36 | 5.28 |
| At economizer inlet ....in. water | 1.28 | 1.93 | 2.03 | 2.74 | 3.17 | 4.21 | 2.34 | 2.37 | 4.42 | 4.99 | 5.76 | 6.95 | 5.64 |
| At air heater inlet....in. water | 1.10 | 1.67 | 1.81 | 2.44 | 2.84 | 3.83 | 2.08 | 1.98 | 3.65 | 4.41 | 5.13 | 6.26 | 5.07 |
| At economizer outlet ....in. water | 1.69 | 2.78 | 2.75 | 3.67 | 4.25 | 5.48 | 3.25 | 3.07 | 5.57 | 6.96 | 8.04 | 9.63 | 6.96 |
| At air heater outlet ....in. water | 1.17 | 1.69 | 1.84 | 2.49 | 2.85 | 3.83 | 2.09 | 2.19 | 3.97 | 4.45 | 5.15 | 6.26 | 5.38 |
| At I.D.F. inlet ....in. water | 1.88 | 3.06 | 3.13 | 4.06 | 4.73 | 6.75 | 3.53 | 3.60 | 6.50 | 7.75 | 8.87 | 10.57 | 8.08 |
| At I.D.F. outlet ....in. water | 0.31 | 0.43 | 0.40 | 0.27 | 0.25 | 0.26 | 1.32 | 0.30 | 0.25 | 0.15 | 0.07 | 0.13 | 0.06 |
| At base of stack ....in. water | 0.69 | 0.61 | 0.53 | 0.53 | 0.52 | 0.51 | 0.59 | 0.65 | 0.60 | 0.62 | 0.57 | 0.61 | 0.63 |
| **Draft Drop** | | | | | | | | | | | | | |
| Through boiler ....in. water | 0.78 | 1.62 | 1.68 | 2.25 | 2.68 | 3.42 | 2.03 | 2.05 | 3.65 | 4.44 | 5.14 | 6.20 | 5.06 |
| Through economizer ....in. water | 0.41 | 0.85 | 0.72 | 0.93 | 1.08 | 1.27 | 0.91 | 0.70 | 1.15 | 1.97 | 2.28 | 2.68 | 1.32 |
| Through air heater ....in. water | 0.07 | 0.02 | 0.03 | 0.05 | 0.01 | 0.00 | 0.01 | 0.21 | 0.32 | 0.04 | 0.02 | 0.00 | 0.31 |
| Through cinder catcher ....in. water | 0.38 | 0.18 | 0.13 | 0.26 | 0.27 | 0.25 | 0.27 | 0.35 | 0.35 | 0.47 | 0.50 | 0.48 | 0.57 |
| Through I.D. fan ....in. water | 1.57 | 2.63 | 2.73 | 3.79 | 4.48 | 6.49 | 3.21 | 3.30 | 6.25 | 7.60 | 8.80 | 10.44 | 8.02 |

### TEMPERATURES, FAN SPEEDS

| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| **Temperatures—°F.** | | | | | | | | | | | | | |
| Steam .... | 688 | 691 | 693 | 716 | 718 | 728 | 682 | 688 | 695 | 708 | 719 | 740 | 700 |
| Moisture in steam ....% | 0.35 | 0.72 | 1.67 | 0.28 | 0.50 | 0.60 | 0.60 | 0.80 | 1.20 | 0.70 | 0.70 | 1.72 | 1.60 |
| Superheat ....° | 272.7 | 272.6 | 274.6 | 297.3 | 299.0 | 309.9 | 263.4 | 269.6 | 275.4 | 285.2 | 296.2 | 318.0 | 278.0 |
| Air surrounding boiler (wet) .... | 58 | 68 | 69 | 68 | 69 | 71 | 72 | 83 | 70 | 70 | 70 | 70 | 76 |
| Air surrounding boiler (dry) ....T-1 | 77 | 84 | 83 | 81 | 85 | 85 | 75 | 95 | 90 | 86 | 85 | 82 | 90 |
| Air entering air heater ....T-2 | 90 | 104 | 107 | 105 | 109 | 109 | 104 | 99 | 98 | 113 | 113 | 112 | 99 |
| Air leaving air heater ....T-3 | 331 | 161 | 214 | 204 | 197 | 211 | 180 | 185 | 180 | 185 | 184 | 189 | 214 |
| Air and coal leaving mill....T-4 | 100 | 117 | 107 | 119 | 118 | 125 | 103 | 104 | 112 | 102 | 101 | 101 | 110 |
| Furnace ....T-5 | ..... | 1737 | 1796 | 1769 | 1745 | 1714 | 1690 | 1737 | 1841 | 1893 | 1868 | 1848 | 1886 |
| Gases leaving boiler ....T-6 | 490 | 550 | 560 | 580 | 593 | 600 | 565 | 565 | 600 | 643 | 655 | 660 | 625 |
| Gases leaving economizer....T-7 | 221 | 243 | 223 | 239 | 245 | 253 | 225 | 229 | 248 | 259 | 260 | 267 | 252 |
| Gases leaving air heater ....T-8 | 294 | 188 | 231 | 236 | 241 | 242 | 225 | 225 | 224 | 227 | 227 | 241 | 256 |
| F.W. entering boiler ....T-9 | 286 | 284 | 268 | 291 | 300 | 318 | 281 | 283 | 288 | 297 | 305 | 307 | 292 |
| F.W. entering economizer ....T-10 | 184 | 175 | 177 | 179 | 176 | 181 | 178 | 177 | 175 | 182 | 180 | 166 | 180 |
| Fuel ....T-12 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 |
| 1st pass below superheater .... | 1169 | 1052 | ..... | ..... | ..... | ..... | 1176 | 1348 | 1392 | ..... | ..... | ..... | 1403 |
| 1st pass above superheater .... | 914 | 1013 | 989 | ..... | ..... | ..... | 986 | 1050 | 1062 | 1169 | 1081 | 1088 | 1116 |
| **Fan Speeds—R.P.M.** | | | | | | | | | | | | | |
| Induced draft .... | 455 | 450 | 451 | 453 | 450 | 710 | 450 | 450 | 711 | 710 | 710 | 708 | 710 |
| Forced draft .... | * | 450 | 451 | 453 | 455 | 455 | 450 | 450 | 450 | 710 | 710 | 706 | 710 |

* Fan not in operation.

### ELECTRICAL AUXILIARY POWER DATA

| Run No. | Pulverizing Mills K.W. 1 | 2 | 3 | 4 | Total | Coal Feeder Motor K.W. 1 | 2 | 3 | 4 | Total | Inner Cone Drive K.W. 1 | 2 | 3 | 4 | Total | F.D. Fan K.W. | I.D. Fan K.W. | Total K.W. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 ...... | 46.4 | * | 53.6 | 54.4 | 154.4 | .0405 | * | .0324 | .0416 | .1145 | .0975 | * | .0875 | .1200 | .3050 | * | 85.0 | 239.80 |
| 5 ...... | 57.6 | * | 54.6 | 55.7 | 167.9 | .0863 | * | .1003 | .0734 | .2600 | .0980 | * | .0790 | .0780 | .2550 | 24.1 | 94.0 | 286.52 |
| 7 ...... | 50.0 | 66.7 | 52.0 | 60.0 | 228.7 | .0876 | .0852 | .0871 | .0830 | .3429 | .0890 | .0730 | .0820 | .1000 | .3440 | 25.3 | 144.0 | 378.68 |
| 4 ...... | 56.7 | * | 59.0 | 62.3 | 178.0 | .1021 | * | .1034 | .1038 | .3093 | .0990 | * | .0920 | .0910 | .2820 | 28.3 | 87.5 | 294.39 |
| 3 ...... | 52.0 | 54.0 | 55.5 | 54.0 | 215.5 | .0803 | .0822 | .0786 | .0767 | .3178 | .1000 | .1100 | .0970 | .1000 | .4070 | 26.6 | 100.0 | 342.82 |
| 1 ...... | 56.3 | 65.3 | 58.4 | 57.9 | 237.9 | .0940 | .0891 | .0987 | .0905 | .3723 | .0840 | .1370 | .1080 | .1080 | .4370 | 38.8 | 338.0 | 615.51 |
| 6 ...... | 68.8 | 65.2 | 69.2 | 64.4 | 267.6 | .0880 | .0864 | .0878 | .0896 | .3518 | .1050 | .1100 | .0940 | .1100 | .4190 | 132.2 | 410.0 | 810.57 |
| 2 ...... | 60.2 | 69.1 | 65.1 | 63.8 | 258.2 | .0881 | .0860 | .0932 | .0864 | .3537 | .0860 | .1060 | .1000 | .0940 | .3860 | 120.0 | 395.0 | 773.94 |

* S.W. burner shut down.

TABLE II—DATA OF TESTS (Continued)

| REFUSE, EVAPORATION, EFFICIENCY | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run No. | 9 | 5 | 7a | 7b | 7c | 7d | 4 | 3 | 1 | 6a | 6b | 6c | 2 |
| Date, November, 1929 | 22 | 12–13 | 14 | 14 | 14 | 14 | 11–12 | 8–9 | 6–7 | 13 | 13 | 14 | 7–8 |
| **Refuse** | | | | | | | | | | | | | |
| Refuse, % of fuel (dry) % | 7.82 | 9.30 | 7.83 | 7.62 | 7.67 | 7.44 | 7.82 | 6.58 | 9.96 | 7.84 | 6.80 | 8.04 | 7.90 |
| Percent combustible in refuse % | 16.74 | 20.60 | 10.84 | 8.29 | 9.01 | 6.20 | 22.48 | 13.42 | 16.58 | 23.10 | 11.28 | 25.00 | 24.25 |
| Carbon burned per lb. of fuel (dry) lb. | 0.821 | 0.812 | 0.830 | 0.832 | 0.832 | 0.834 | 0.827 | 0.835 | 0.809 | 0.826 | 0.836 | 0.824 | 0.827 |
| **Evaporation** | | | | | | | | | | | | | |
| Actual evap. per lb. of fuel (dry) lb. | 11.21 | 10.67 | 10.82 | 10.82 | 10.82 | 10.82 | 10.53 | 10.91 | 10.30 | 10.62 | 10.62 | 10.62 | 10.61 |
| Equiv. evap. per lb. of fuel (dry) lb. | 12.72 | 12.14 | 12.48 | 12.32 | 12.28 | 12.12 | 11.97 | 12.40 | 11.68 | 12.03 | 11.95 | 12.06 | 12.02 |
| Equiv. evap. per sq. ft. heating surface/hr. lb. | 6.26 | 9.20 | 10.35 | 10.21 | 10.15 | 10.05 | 10.27 | 10.33 | 13.40 | 15.17 | 15.10 | 15.21 | 15.50 |
| Units of evap. absorbed per sq. ft. of boiler heating surface per hr. U.E. | 6.07 | 8.95 | 10.04 | 9.95 | 9.86 | 9.75 | 9.95 | 10.02 | 13.02 | 14.71 | 14.64 | 14.73 | 15.04 |
| **Efficiency** | | | | | | | | | | | | | |
| Comparative efficiency of boiler, superheater, and furnace not including air heater % | 83.6 | 79.4 | 80.6 | 79.4 | 79.1 | 77.6 | 77.1 | 79.5 | 76.6 | 77.3 | 76.7 | 77.1 | 77.1 |
| Overall efficiency % | 91.4 | 89.1 | 89.3 | 89.9 | 90.5 | 90.5 | 86.3 | 89.0 | 86.7 | 87.2 | 87.4 | 89.4 | 87.3 |
| **Efficiencies Corrected for Energy Consumed by Pulverizing Mills, Inner Cones, & Mill Feeders** | | | | | | | | | | | | | |
| Comparative efficiency of boiler, superheater, and furnace, not including air heater % | 82.1 | 78.3 | 79.4 | 78.3 | 78.0 | 76.5 | 76.2 | 78.4 | 75.6 | 76.4 | 75.8 | 76.1 | 76.2 |
| Overall efficiency | 89.7 | 87.9 | 88.0 | 88.7 | 89.2 | 89.2 | 85.4 | 87.8 | 85.6 | 86.2 | 86.4 | 88.4 | 86.4 |

tween the center and end drums which varied from two to twenty-four inches of water. With the cooperation of the boiler manufacturer the situation was entirely corrected by inserting eleven four-inch pressure equalizing nipples from each end drum to the middle drum. The further desirable feature of a low water level in the middle drum was achieved by inserting cross-over pipes in the middle drum connecting several of the water circulating loops so that the middle drum was bypassed. See figure 5.

### *Test Procedure*

The test was conducted during the period Nov. 6 to 22, 1929.

All items of observations reported herein were obtained in the generally accepted and approved manner.

Some amplifications to insure the accuracy of water and coal measurements may be of sufficient interest to report at some length.

The feed water was determined by inserting two calibrated Venturi meters on the inlet side of the economizer. These meters were connected in parallel and the sizes were such that either one or the other could be employed to give a high mercury differential at any given rating. Thus, for ratings below 200,000 lb. per hr., the water was measured with the smaller meter and for ratings between 200,000 and 400,000 lb. per hr. the larger meter was used.

The Venturi manometers were placed beside the hand wheel of the feed valve and during a test run all automatic feed regulators were disconnected and the rate of feed was under continuous manual control to maintain the chosen rate of flow. Changes in the drum water level were compensated by slight adjustments in combustion conditions with occasional timed changes in the set flow.

Considerable thought was devoted to means for determining coal quantities with the desired degree of accuracy. In stoker tests the ever present difficulty is with the quantity and condition of fuel on the grate at the beginning and end of a test. For this reason it is necessary to conduct tests of long duration to average down possible errors in fuel quantities. With many powdered coal installations a similar difficulty presents itself in the level of coal over the extended surface of a boiler bunker at the beginning and end of tests. Coal does not flow evenly, and irregular heaps and mounds together with inaccessibility complicate the problem of fuel measurement.

These difficulties were overcome in the tests on Boiler No. 81 by the following procedure: After weighing the coal in carefully calibrated automatic scales it was distributed to the four mills through special individual chutes as shown in Fig. 7.

The design of the chutes is an outcome of a critical study of the flow conditions in boiler bunkers where the coal appears to form and flow through a narrow funnel-shaped opening while the surrounding mass of coal assumes more or less irregular contours. This suggested the proper shape of the chutes.

As depicted in Fig. 7, the chutes were placed in the bunker in which the level of the coal had been lowered to the top of the pockets serving the mills. Coal was leveled at this elevation and the chutes were allowed to rest on it with the aid of a cross bar footing. At the beginning and end of each run the chutes were filled with coal to about the same point at the top and the elevation of the coal around the chute at its bottom was noted. At no time were the chutes allowed to become empty with the result that the coal elevation around the bottom changed very little.

With this arrangement it was possible to make accurate determinations of hourly coal consumption for relatively short runs.

An unduly large pressure drop through the economizer precluded the possibility of feeding water for a run at 400,000 lb. per hr. even though the mill and burner capacities were fully adequate for this rating. It was also impracticable to run a test for an evaporation of less than 200,000 lb. per hr. with all four burners as the low velocities would cause unstable flame conditions. For ratings lower than 200,000 lb. per hr., three-burner operation was employed. The lowest rating conducted with three

(*Continued on page 29*)

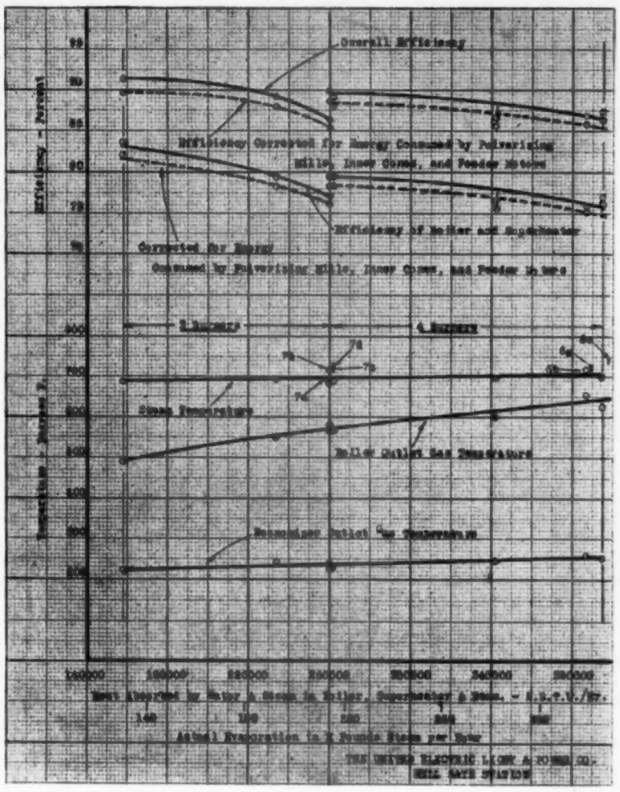


**Fig. 8—Efficiencies and gas temperatures at various ratings for 3-burner and 4-burner operation.**

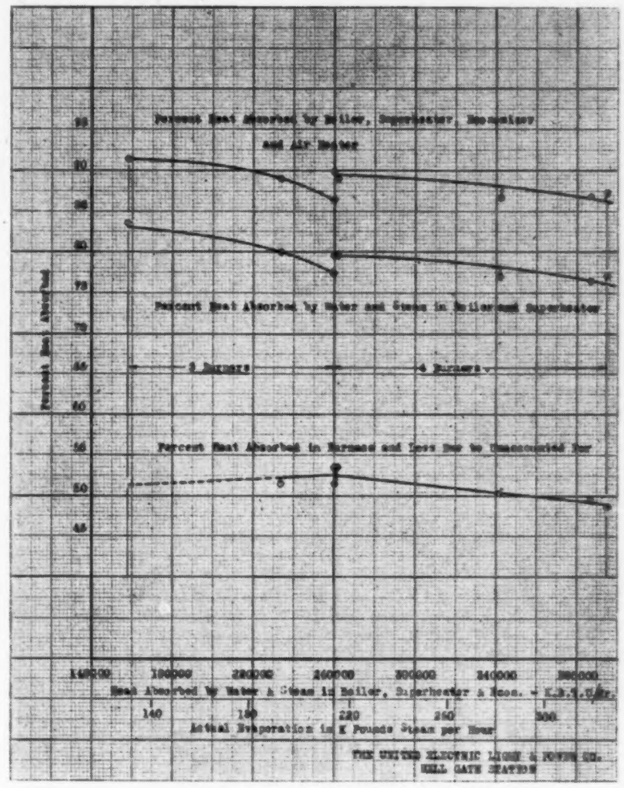


**Fig. 9—Heat absorbed by boiler, superheater, economizer and air heater at various ratings with 3-burner and 4-burner operation.**

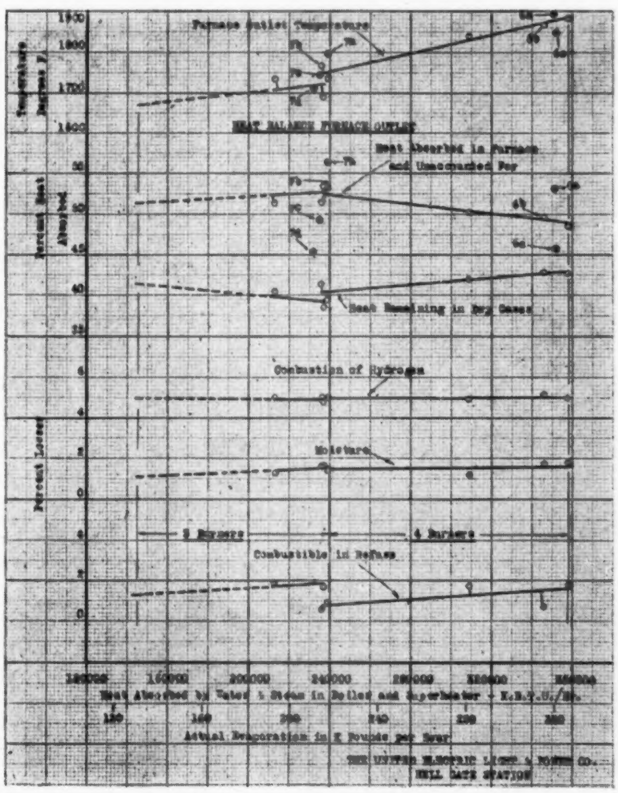


**Fig. 10—Heat balance at furnace outlet with 3-burner and 4-burner operation.**

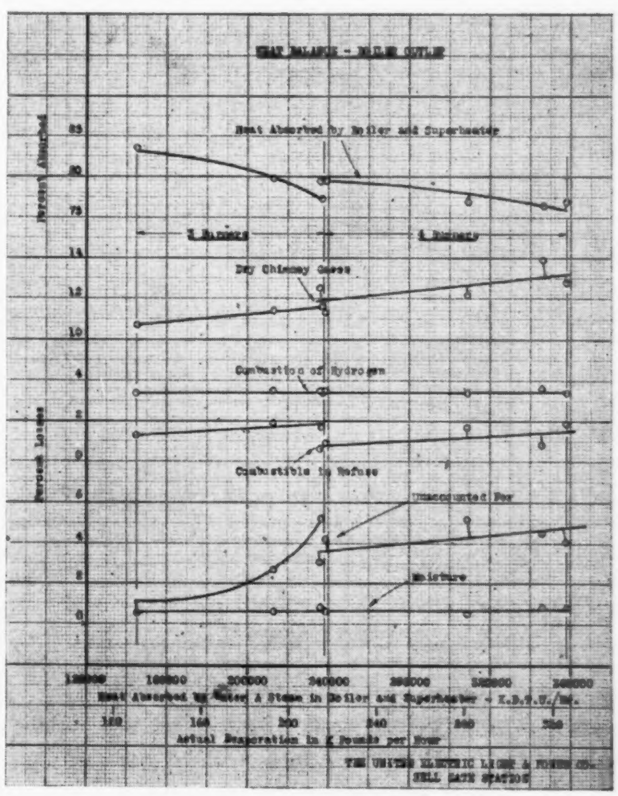


**Fig. 11—Heat balance at boiler outlet with 3-burner and 4-burner operation.**

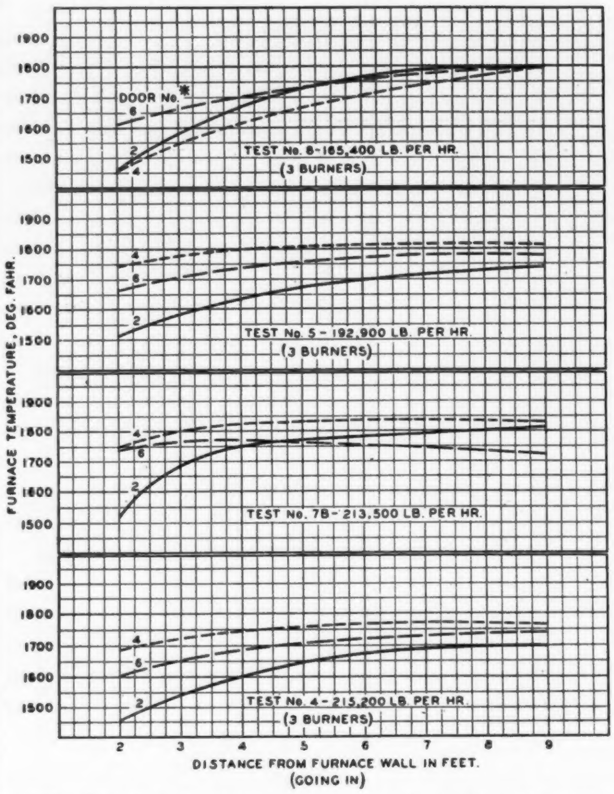



**Fig. 12—Furnace temperature at various ratings for tests Nos. 8, 5, 7B and 4.**

(Corrected for thermocouple and potentiometer calibration, and for cold junction temperature. Corrections and temperatures corresponding to potentiometer millivolt reading taken from curves furnished by Combustion Engineering Corporation.)

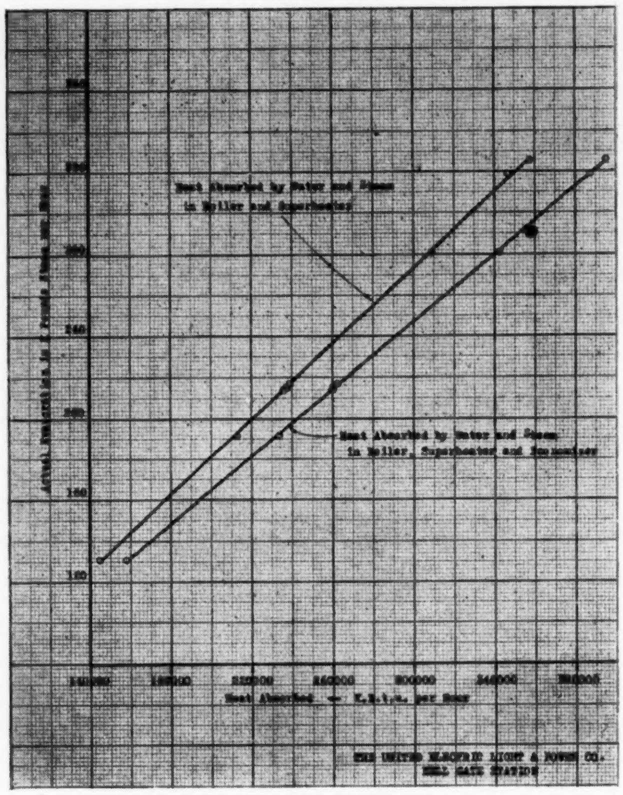


**Fig. 13—Heat absorption of different elements of unit at various ratings.**

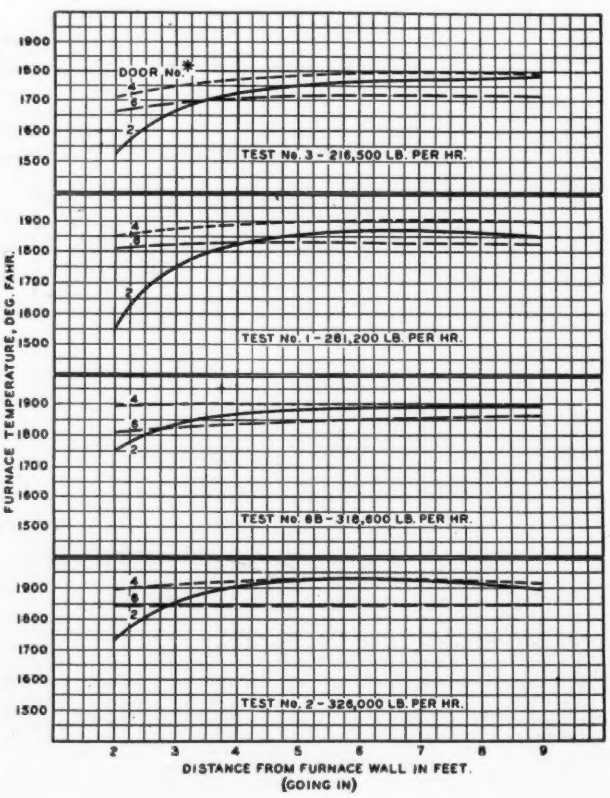



**Fig. 14—Furnace temperature at various ratings for tests Nos. 3, 1, 6B and 2.**

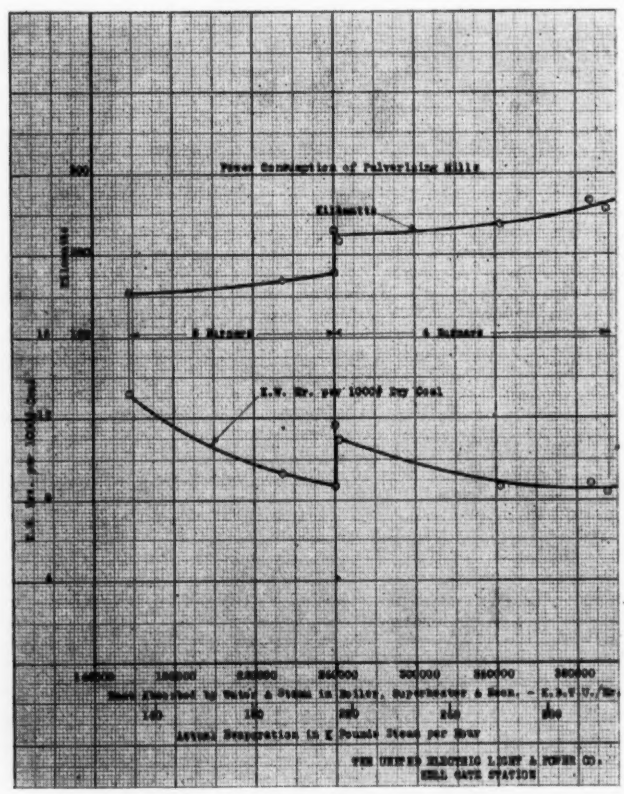


**Fig. 15—Power consumption of pulverizing mills.**

* Numbers on curves in figs. 12 and 14 indicate doors through which readings were taken.

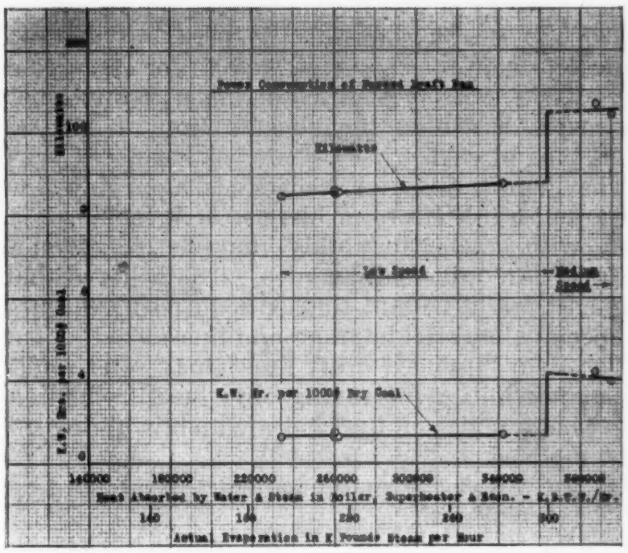


Fig. 16—Power consumption of forced draft fan.

burners was 131,000 lb. per hr. and for this purpose it was necessary to shut down the forced draft fan. The induced draft fan was operated with the inlet vanes practically shut. The stack damper was also nearly closed, the secondary air dampers at the burners were closed tight and the primary air, drawn from the atmosphere around the mills, was restricted.

In runs Nos. 6 and 7, the carbon-dioxide percentage was varied in several steps to determine the effect of different amounts of excess air on superheat, gas temperatures, and heat absorption.

Combustion Engineering Corporation made concurrent observations of furnace temperatures at various ratings. The data furnished by them are represented by curves shown in Figs. 12 and 14.

### *Computations*

The performance of the boiler was computed in

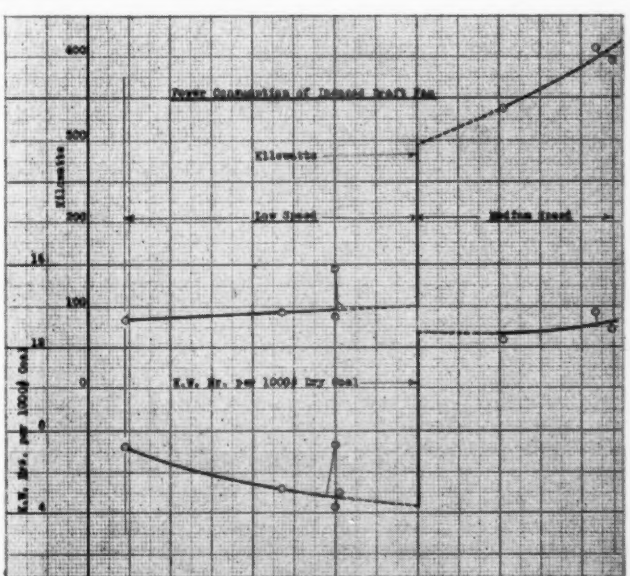


Fig. 17—Power consumption of induced draft fan.

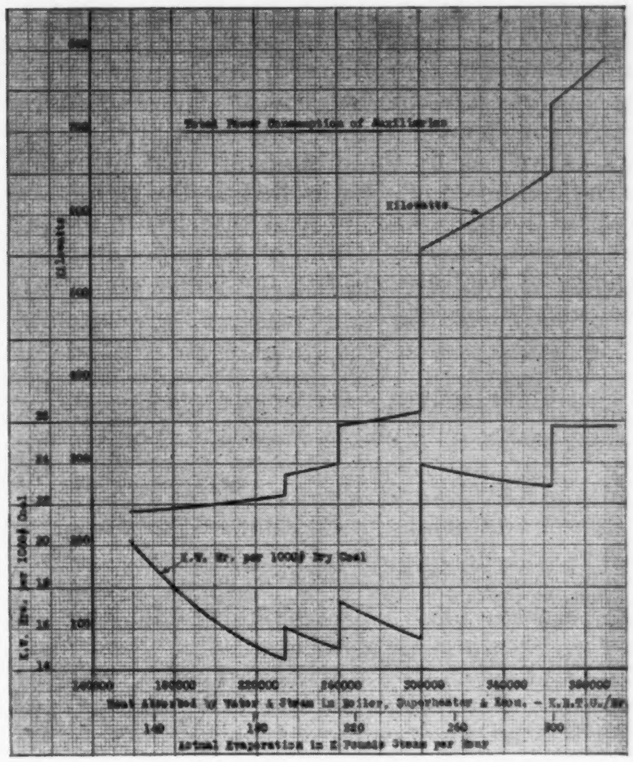


Fig. 18—Total power consumption of auxiliaries.

accordance with the A. S. M. E. Boiler Test Code.

In the determination of the performance of the air preheater it was necessary to modify the method of computation given in the Code because of the difference in the arrangement of the air preheater with respect to the economizer. The Code considers the case where they are in series, while in this case they are placed in parallel.

Table 2 gives in tabular form results of the tests. The auxiliary power characteristics are represented by graph as well as in tabular form.

### *Discussion of Results*

Graphical presentation of the test results brings out a striking difference in the performance of the boiler when three or four burners are in operation. The two outstanding factors that have a direct bearing on this effect are the performance of mills and combustion conditions in the furnace. To obtain a given rate of evaporation with the use of only three burners, each mill has to grind a larger quantity of coal than it would if four burners were used. Naturally the coal fineness is impaired somewhat. Furthermore, the flame from the three burners does not fill the furnace and turbulence is somewhat diminished. These conditions are not conducive to proper burning of the comparatively coarse coal and a higher loss results due to increased combustible in the refuse.

Another peculiar characteristic of three burner operation is illustrated in Fig. 10 which shows that the percentage of heat absorbed in the furnace decreases with the lowering of rating which is contrary to the trend established by four burner operation. This is in spite of the fact that the furnace temperature curve in both cases is somewhat sim-

ilar. The seeming anomaly is an outcome of the fact that the quantity of secondary air passed through the idle burner to keep it cool partly stratifies and increases the per cent of excess air so that the furnace temperature is influenced by these factors as well as by the diminished heat liberation.

The combined effect was that as the rating was lowered the percentage of heat absorbed in the furnace became smaller while the corresponding percentage of heat absorbed in the boiler and superheater grew larger.

TABLE III

MISCELLANEOUS MAINTENANCE COSTS
BOILERS 81, 82 AND 83

| | Period 1929-1930 470,000 Short Tons Coal | |
|---|---|---|
| | Total Cost Dollars | Dollars per short ton |
| Induced draft fans | 16214 | .0345 |
| Boiler drums, headers, tubes, nipples, drains, valves and fittings | 3476 | .0074 |
| Baffles and flues | 2619 | .0056 |
| Superheaters | 4437 | .0094 |
| Soot blowers and conveyors | 2262 | .0048 |
| Side water walls | 590 | .0013 |
| Outside casings and ash troughs | 288 | .0006 |
| Economizers | 1022 | .0022 |
| Air heaters | 165 | .0004 |
| Automatic scales, bins, belt conveyor, dual drive MG sets | 2897 | .0062 |
| Burners | 1796 | .0038 |
| Mills and feeders | 15892 | .0338 |

Shortly after this series of tests was completed, the economizer manufacturer made alterations in the grouping of the tube connections so that the pressure drop was lowered considerably. This made possible ratings of from 400,000 to 450,000 lb. per hr. throughout the winter peak period with a heat release of about 32 to 36 thousand B.t.u. per cu. ft. of furnace volume.

At the time of the test, soot blower equipment was not yet installed around the superheater, hence the steam temperature level was somewhat lower than it has been since soot blowers have been in use.

Table 3 shows some of the pertinent maintenance costs on boilers 81, 82 and 83 for the period 1929-1930. These costs include material and labor and were based on the consumption of 470,000 short tons of coal.

The item "mills and feeders" is agreeably low for a unit mill. However, the use of West Virginia coal, with good grindability characteristics, tends to favor low mill maintenance. It is believed that this cost might be still further reduced by the use of special alloy steel hammer and liners.

The item "induced draft fans" may offer additional possibility for savings by the introduction of wearing plates on the blades which is at present contemplated.

On the whole the maintenance costs are in line with expectations.

One of the opportunities for lowering costs by use of pulverized fuel equipment is offered by its adaptability to the use of slack size coal. In addition to improvement in grinding and feeding conditions, the fuel costs for equal heat values may be lowered sufficiently to more than offset the mill grinding power and maintenance costs.

### *Conclusions*

In general the test performance of boiler 81 can be considered quite satisfactory. It represents an advance over earlier installations and the progressive improvements in combustion performance at Hell Gate are strikingly illustrated in Fig. 19. This gives a comparison of test efficiencies between boiler 81 and stoker boilers comprising previous installations at Hell Gate as reported by Mr. H. W. Leitch in the A. S. M. E. transactions of 1926.

Flatness of the efficiency curve of boiler 81 stands out most prominently which renders this boiler particularly valuable for heavy loads on the station.

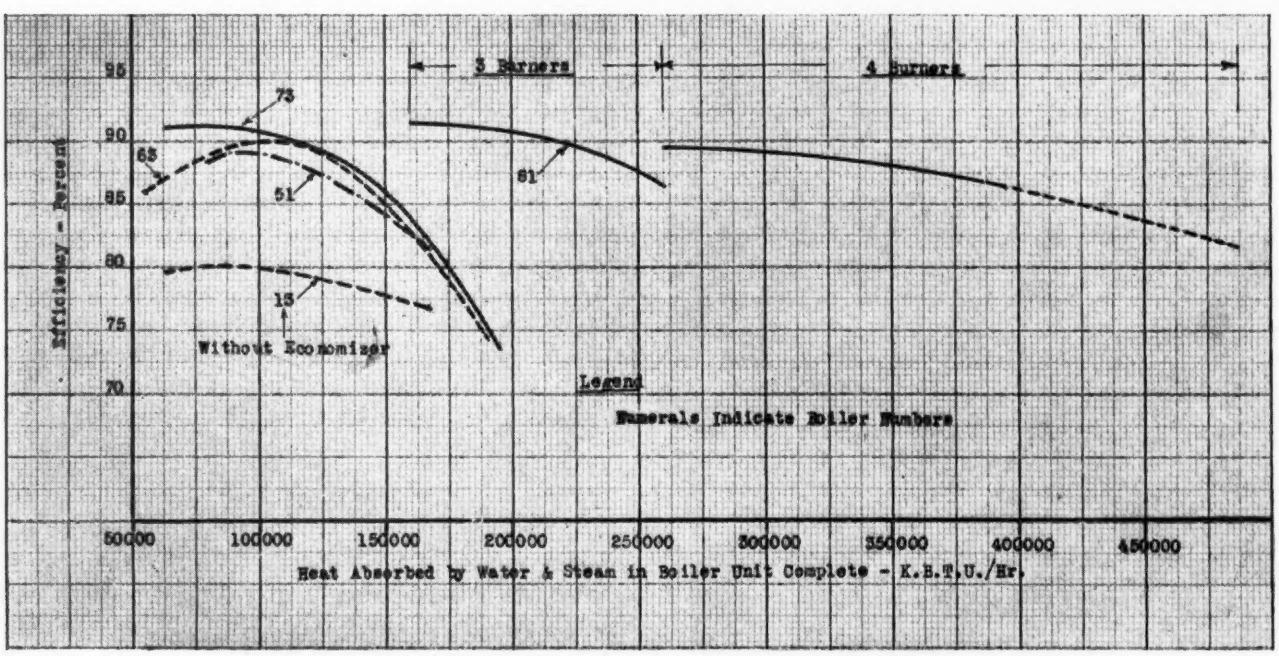



**Fig. 19—Overall efficiency of various boilers at Hell Gate Station including boiler No. 81**

# Combustion Heat Balance*

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**This is the second of a group of four articles begun in May COMBUSTION on the subject of the properties of fuels and combustion calculations. The present article discusses and summarizes the relations to be applied in analyzing the performance of an actual furnace under given conditions in order to determine the efficiency of the furnace and to obtain data for the design of similar furnaces. These relations are summarized in Table 4, while Tables 1, 2 and 3 contain the basic numerical data which may be utilized in combustion calculations.**

COMBUSTION is the chemical combination of elements of a fuel with oxygen generally supplied as one of the constitutents of atmospheric air. During the process, heat is evolved. Some of the heat is immediately radiated to surrounding objects while the remainder raises the temperature of the products of combustion above that of the fuel and air originally. Heat for useful purposes may be obtained by intercepting more or less of the radiant heat and by abstracting sensible heat from the hot products of combustion before discharging them into the atmosphere.

It may be desirable to limit the maximum temperature reached during combustion of a fuel in a furnace in order to avoid slagging the ash from the fuel burned or injury to the furnace refractories or exposure of the material heated to too high a temperature. The temperature during combustion can evidently be limited by supplying an excess of air over that theoretically required for combustion so that the products of combustion will be sufficient in amount to absorb the heat available without exceeding the desired maximum temperature. In some instances, products of combustion have been recirculated for this purpose after being cooled to the temperature at which they would otherwise have been discharged into the atmosphere. By providing watercooled surfaces in the furnace or by otherwise increasing the absorption of radiant heat from the flames, the furnace outlet temperature may be reduced without increasing the percentage of excess air or recirculating products of combustion.

It may also be desirable to limit the minimum temperature to which the products of combustion are cooled before discharging them into the atmosphere, in order to prevent condensation of moisture and avoid corrosion due to sulphur from the fuel. In heating value determinations upon fuel samples, however, it is customary to cool the products of combustion to room temperature so that a considerable portion if not all the water vapor resulting from combustion of the hydrogen and present as water in the fuel is condensed to liquid. In an actual furnace, therefore, the heat available is generally less than the calorimeter heating value of the fuel by the latent heat of this water vapor. It may also be less by reason of incomplete combustion of the fuel caused by a restricted furnace volume or by lack of thorough mixing of fuel and air. On the other hand, preheating the air for combustion increases the heat available.

In combustion calculations, we are therefore concerned with the heating value and compostion of the fuel burned, with the quantities of oxygen and of atmospheric air theoretically required and actually supplied for combustion, with the temperature and sensible heat of this air, with the quantity of heat actually produced by combustion and the portions radiated from and remaining as sensible heat in the products of combustion, with the composition, quantity and temperature of these products and with the change in temperature as heat is abstracted therefrom, with the dew point temperature of the products of combustion and with the latent heat of the moisture condensed in cooling the products below the dew point. We may also be concerned with the ignition temperature of the fuel, the velocity of flame propagation, etc., in order to design properly the furnace and its auxiliary equipment, but these will not be dealt with in the present article which will be limited to combustion calculations useful in working up a heat balance for a given furnace.

*Basis for Combustion Calculations*

The comparative ease with which products of combustion can be analyzed to determine the proportions by volume of the dry constituents, as explained in the previous article entitled "Ther-

mal Properties of Gaseous Mixtures," and the commercial development of automatic devices for continuously recording the percentage of carbon dioxide in stack gases from industrial furnaces, have led to combustion conditions in a given furnace being judged by the composition of the products of combustion. This information may be supplemented by a chemical analysis and a heating value determination for the fuel burned, by humidity measurements upon the air supplied for combustion, by temperature measurements of the air and of the products of combustion and by such weights of fuel, ashes, etc., as may be necessary to make a complete heat balance for the furnace in question. An analysis of the results so obtained from various furnaces by test or operating experience furnishes design data for estimating the probable performance of other furnaces under more or less similar conditions.

The basis for such an analysis is found in the chemical equations for the combination of oxygen with carbon, sulphur, and hydrogen or with the various compounds of these elements found in gaseous fuels, as given in Table I.

The first equation, for example, shows that one mole, or 12 lb., of carbon combines with one mole, or 32 lb., of oxygen to form one mole, or 44 lb., of carbon dioxide with the liberation of 174,200 B.t.u. under constant pressure combustion at 68 fahr. The heat produced per pound of carbon is evidently 174,200/12 = 14,520 B.t.u. If the combustion is incomplete, however, the second equation shows that the combination of one-half mole, or 16 lb., of oxygen with 12 lb. of carbon to form one mole, or 28 lb., of carbon monoxide liberates 52,500 B.t.u. only. This is equivalent to 52,500 /12 = 4380 B.t.u. per lb. of carbon, or 10,140 B.t.u. per lb. less than for complete combustion.

As another example, consider the seventh equation for the combustion of methane. One mole, or 16 lb., of methane combines with two moles, or 64 lb., of oxygen to form one mole, or 44 lb., of carbon dioxide and two moles, or 36 lb., of water with the liberation of 383,200 B.t.u. when combustion takes place under constant pressure with the methane and oxygen originally at room temperature and the products finally reduced to the same temperature. The volume of oxygen required is twice that of the methane burned when measured at the same pressure and temperature. For every pound of methane, 64 / 16 = 4 lb. of oxygen are required. The heat liberated per pound of methane is 383,200 / 16 = 23,900 B.t.u. The heat liberated per cubic ft. of methane will vary with its pressure, temperature and humidity. In moisture saturated gas at 60 fahr. under 30 inches of mercury, one mole of the dry gas has a volume of 385.1 cu. ft. Hence, the heat produced per cubic foot of methane under these conditions is 383,200 / 385.1 = 995 B.t.u.

### *Air Theoretically Required for Complete Combustion*

By application of the chemical equations in Table I., the oxygen and therefore the atmospheric air theoretically required for complete combustion of a fuel of known composition can be calculated.

For solid and liquid fuels, the composition is usually given on a weight basis, and the weight or volume of atmospheric air required for combustion is usually desired per unit weight of fuel. If C. H, S and O represent the weights of carbon, hydrogen, sulphur and oxygen respectively in unit weight of fuel, then the weight of dry air theoretically required for complete combustion of unit weight of fuel is evidently

$$A_w = \frac{1}{0.232}\left[\frac{44}{12}C + \frac{16}{2}H + \frac{32}{32}S - O\right]$$

$$= \frac{1}{0.232}\left[2.67\,C + 8(H - \frac{O}{8}) + S\right]$$

where 0.232 is the weight fraction of oxygen in dry atmospheric air, see previous article on "Thermal Properties of Gaseous Mixtures." The moles of dry air theoretically required for complete combustion of unit weight of a solid or liquid fuel are evidently given by

$$A_m = \frac{1}{0.21}\left[\frac{C}{12} + \frac{H}{4} + \frac{S}{32} - \frac{O}{32}\right]$$

where 0.21 is the volume fraction of oxygen in dry atmospheric air.

For a gaseous fuel, the above formulas are not directly applicable unless the usual volumetric composition is reduced to an equivalent ultimate composition by weight. This, however, is unnecessary because the oxygen and atmospheric air theoretically required can be readily calculated from the volumetric composition of the gaseous fuel by the use of the chemical equations in Table I. To facilitate such calculations, Table II has been prepared giving the number of moles and the weight in pounds of oxygen, atmospheric nitrogen and dry atmospheric air theoretically required for combustion of one mole of each gas listed. In preparing Table II, atmospheric air has been taken as having an equivalent molecular weight of 28.966 and to be composed of 21 per cent oxygen and 79 per cent nitrogen by volume. For this "atmospheric nitrogen," an equivalent molecular weight of 28.16 has been used as derived in the article on "Thermal Properties of Gaseous Mixtures."

A formula similar to those given for solid and liquid fuels can be written for the moles of dry air theoretically required for complete combustion of one mole of dry gas as follows:

$$A_m = \frac{1}{0.21}\left[\begin{array}{l}0.5\,H_2 + 1.5\,H_2S + 0.5\,CO + 2CH_4 \\ \quad + 3.5\,C_2H_6 + 3\,C_2H_4 + \text{etc.}\end{array}\right]$$

where $H_2$, $H_2S$, $CO$, $CH_4$, $C_2H_6$, $C_2H_4$, etc. represent the volume fractions of these constituents of the fuel gas as determined by analysis. Usually, however, the dry air theoretically required for a mixture of gases is determined without the aid of any

formula simply by multiplying the mole fractions of the constituents by the appropriate values taken from Table II. and then adding the products to get

TABLE I. COMBUSTION REACTIONS

For combustion under constant pressure at 68 fahr. to form gaseous $CO_2$ and $SO_2$ and liquid $H_2O$

Carbon (Complete Combustion)
$$C + O_2 = CO_2 + 174{,}200 \text{ B.t.u.}$$
Carbon (Incomplete Combustion)
$$C + \frac{1}{2} O_2 = CO + 52{,}500 \text{ B.t.u.}$$
Sulphur
$$S + O_2 = SO_2 + 124{,}700 \text{ B.t.u.}$$
Hydrogen
$$H_2 + \frac{1}{2} O_2 = H_2O + 123{,}000 \text{ B.t.u.}$$
Hydrogen Sulphide
$$H_2S + \frac{3}{2} O_2 = H_2O + SO_2 + 238{,}400 \text{ B.t.u.}$$
Carbon Monoxide
$$CO + \frac{1}{2} O_2 = CO_2 + 121{,}700 \text{ B.t.u.}$$
Methane
$$CH_4 + 2\,O_2 = CO_2 + 2\,H_2O + 383{,}200 \text{ B.t.u.}$$
Ethane
$$C_2H_6 + \frac{7}{2} O_2 = 2\,CO_2 + 3\,H_2O + 663{,}100 \text{ B.t.u.}$$
Propane
$$C_3H_8 + 5\,O_2 = 3\,CO_2 + 4\,H_2O + 947{,}300 \text{ B.t.u.}$$
Butane
$$C_4H_{10} + \frac{13}{2} O_2 = 4\,CO_2 + 5\,H_2O + 1{,}230{,}100 \text{ B.t.u.}$$
Pentane
$$C_5H_{12} + 8\,O_2 = 5\,CO_2 + 6\,H_2O + 1{,}508{,}900 \text{ B.t.u.}$$
Ethylene
$$C_2H_4 + 3\,O_2 = 2\,CO_2 + 2\,H_2O + 597{,}600 \text{ B.t.u.}$$
Propylene
$$C_3H_6 + \frac{9}{2} O_2 = 3\,CO_2 + 3\,H_2O + 894{,}200 \text{ B.t.u.}$$
Butylene
$$C_4H_8 + 6\,O_2 = 4\,CO_2 + 4\,H_2O + 1{,}165{,}000 \text{ B.t.u.}$$
Pentylene
$$C_5H_{10} + \frac{15}{2} O_2 = 5\,CO_2 + 5\,H_2O + 1{,}446{,}500 \text{ B.t.u.}$$
Acetylene
$$C_2H_2 + \frac{5}{2} O_2 = 2\,CO_2 + H_2O + 561{,}600 \text{ B.t.u.}$$
Benzol
$$C_6H_6 + \frac{15}{2} O_2 = 6\,CO_2 + 3\,H_2O + 1{,}417{,}000 \text{ B.t.u.}$$
Toluol
$$C_7H_8 + 9\,O_2 = 7\,CO_2 + 4\,H_2O + 1{,}684{,}800 \text{ B.t.u.}$$

the moles of dry air per mole of dry gaseous mixture. The results may then be reduced to one cubic foot of the gaseous mixture under any desired conditions by dividing by the volume of one mole of dry gas under those conditions. Thus, for moisture saturated gas at 60 fahr. under 30 inches of mercury, divide by 385.1 cu. ft. and for a dry gas mixture at 68 fahr. under 29.92 inches of mercury, divide by 385.3 cu. ft., as derived in the article on "Composition and Heating Value of Fuels."

### *Dry Products of Combustion*

In an actual furnace, the amount of products of combustion does not correspond to the quantity of air calculated as above explained because it is necessary to supply "excess air" above this theoretical minimum, otherwise, the combustion would not be complete. That is, complete combustion can be approached only with some "free oxygen" in the products. Even with excess air, however, some carbon monoxide will often be formed and some combustible material will generally escape unburnt from the furnace. The products of combustion will therefore consist of carbon dioxide, carbon monoxide, oxygen, nitrogen, water vapor and some unburnt fuel.

In case of coal, the unburnt fuel is mostly carbon mixed with ash, although some of the volatile hydrocarbons may escape unburnt if not thoroughly mixed with oxygen after being distilled from the fuel in the furnace. Assume the weights of ashes, clinkers and flue dust to be $R_1$, $R_2$ and $R_3$ pounds respectively per pound of fuel fired, and let $C_1$, $C_2$ and $C_3$ represent the corresponding weights of carbon per unit weight of refuse. Then the carbon lost in the refuse is

$$C_R = C_1 R_1 + C_2 R_2 + C_3 R_3$$

and the carbon burned per pound of fuel fired is

$$C_B = C - C_R$$

where C is the weight of carbon in one pound of fuel, as found by analysis.

For each pound of coal fired, there will evidently be $C_B/12$ moles of carbon dioxide and carbon monoxide in the products of combustion. There will also be present S/32 moles of sulphur dioxide which, in the analysis of the products, will be absorbed by the caustic potash solution and therefore appear as carbon dioxide in the reported analysis. Hence the apparent number of moles of carbon dioxide plus carbon monoxide equals $(C_B/12 + S/32)$. Denoting the volumetric proportion of carbon dioxide plus carbon monoxide in the dry products of combustion by $(CO_2 + CO)$, the total moles of dry products per pound of coal fired are equal to

$$P_m = \frac{C_B/12 + S/32}{CO_2 + CO} = \frac{C_B + \frac{3}{8} S}{12\,(CO_2 + CO)}$$

This relation applies to liquid as well as to solid fuels other than coal, and can also be applied to gaseous fuels if the weight fractions of carbon and sulphur in the latter are known. In the case of gaseous fuels, however, it is much simpler to determine the moles of products per mole of dry gas in the fuel rather than per unit weight of fuel because this can be done directly from the volumetric analysis of the gaseous fuel. Thus, if we denote the volume fractions in the fuel gas of carbon dioxide, carbon monoxide, hydrogen sulphide, methane, ethane, ethylene, etc., by $CO_2$, $CO$, $H_2S$, $CH_4$, $C_2H_6$, $C_2H_4$, etc., then the total moles of car-

TABLE II. AIR THEORETICALLY REQUIRED FOR COMPLETE COMBUSTION OF ONE MOLE OF GASEOUS FUELS

| Gas | Chemical formula | Oxygen, $O_2$ moles | Oxygen, $O_2$ lb. | Nitrogen, $N_2$ moles | Nitrogen, $N_2$ lb. | Dry air moles | Dry air lb. |
|---|---|---|---|---|---|---|---|
| Hydrogen | $H_2$ | 0.5 | 16 | 1.881 | 53.0 | 2.381 | 69.0 |
| Hydrogen sulphide | $H_2S$ | 1.5 | 48 | 5.643 | 158.9 | 7.143 | 206.9 |
| Carbon monoxide | $CO$ | 0.5 | 16 | 1.881 | 53.0 | 2.381 | 69.0 |
| Saturated hydrocarbons | | | | | | | |
| Methane | $CH_4$ | 2.0 | 64 | 7.524 | 211.9 | 9.524 | 275.9 |
| Ethane | $C_2H_6$ | 3.5 | 112 | 13.167 | 370.8 | 16.667 | 482.8 |
| Propane | $C_3H_8$ | 5.0 | 160 | 18.810 | 529.7 | 23.810 | 689.7 |
| Butane | $C_4H_{10}$ | 6.5 | 208 | 24.453 | 688.6 | 30.953 | 896.6 |
| Pentane | $C_5H_{12}$ | 8.0 | 256 | 30.096 | 847.5 | 38.096 | 1103.5 |
| **Illuminants** | | | | | | | |
| Ethylene | $C_2H_4$ | 3.0 | 96 | 11.286 | 317.8 | 14.286 | 413.8 |
| Propylene | $C_3H_6$ | 4.5 | 144 | 16.929 | 476.7 | 21.429 | 620.7 |
| Butylene | $C_4H_8$ | 6.0 | 192 | 22.572 | 635.6 | 28.572 | 827.6 |
| Pentylene | $C_5H_{10}$ | 7.5 | 240 | 28.215 | 794.5 | 35.715 | 1034.5 |
| Acetylene | $C_2H_2$ | 2.5 | 80 | 9.405 | 264.8 | 11.905 | 344.8 |
| Benzol | $C_6H_6$ | 7.5 | 240 | 28.215 | 794.5 | 35.715 | 1034.5 |
| Toluol | $C_7H_8$ | 9.0 | 288 | 33.858 | 953.4 | 42.858 | 1241.4 |

bon dioxide, carbon monoxide and sulphur dioxide formed therefrom by combustion must equal ($CO_2 + CO + H_2S + CH_4 + 2C_2H_6 + 2C_2H_4 +$ etc.) Denoting as before the volumetric proportion of carbon dioxide plus carbon monoxide in the products of combustion by ($CO_2 + CO$), the total moles of dry products per mole of dry gas fired are equal to

$$P_m = \frac{CO_2+CO+H_2S+CH_4+2C_2H_6+2C_2H_4+\text{etc.}}{CO_2+CO}$$

The moles of products per cubic foot of gas fired can be found by dividing by the volume of one mole of gas under the specified conditions of pressure, temperature and humidity.

Denoting the volume fractions of carbon dioxide, carbon monoxide, oxygen and nitrogen in the dry products of combustion by $CO_2$, CO, $O_2$ and $N_2$ respectively, the number of moles of these constituents per unit weight of solid or liquid fuel or per unit volume of gaseous fuel are:

$CO_2 \times P_m$ moles of carbon dioxide,
$CO \times P_m$ moles of carbon monoxide,
$O_2 \times P_m$ moles of oxygen and
$N_2 \times P_m$ moles of nitrogen.

Multiplying the number of moles of each constituent by the molecular weight of that constituent and adding the products gives the total weight of the dry products of combustion per unit of fuel, namely,

$$P_m = (44\,CO_2 + 28\,CO + 32\,O_2 + 28.16\,N_2) \times P_m$$

The molecular weight of atmospheric nitrogen rather than that of chemically pure nitrogen has been used because the amount of chemically pure nitrogen in the products of combustion from the fuel is negligible in comparison with that from atmospheric air.

For solid and liquid fuels, the above relation is sometimes reduced to the following formula for the weight of products of combustion per pound of fuel fired by substituting the value of $P_m$ previously derived for coal, obtaining

$$P_w = \frac{11\,CO_2 + 7\,CO + 8\,O_2 + 7.04\,N_2}{3\,(CO_2 + CO)}\left(C_B + \frac{3}{8}S\right)$$

Since the sum of the volume fractions of $CO_2$, CO, $O_2$ and $N_2$ is equal to unity, this formula can be further reduced to the following, neglecting the small quantity of 0.04 $N_2$:

$$P_w = \frac{4\,CO_2 + O_2 + 7}{3\,(CO_2 + CO)}\left(C_B + \frac{3}{8}S\right)$$

The correction for sulphur in the fuel is generally given as S / 1.833; but this is incorrect as the preceding derivation shows.

### *Moisture in Products of Combustion*

The moisture associated with dry products of combustion is equal to the sum of the moisture in the air supplied for combustion, that existing as such in the fuel fired and that formed from the hydrogen in the fuel. For solid and liquid fuels, the total moisture per pound of fuel fired is

$$(w\,A_w + M + 9H) \text{ lb. or}$$

$$\left(m\,A_m + \frac{M}{18} + \frac{H}{2}\right) \text{ moles}$$

where M and H are the weight fractions of moisture and hydrogen in the fuel as found by analysis. For gaseous fuels, the total moles of moisture per mole of dry gas are

$m\,A_m - M + H_2 + H_2S + 2CH_4 + 3C_2H_6 + 2C_2H_4$ + etc. where $H_2$, $H_2S$, $CH_4$, $C_2H_6$, $C_2H_4$, etc., represent the volume fractions of these components in the dry fuel gas as found by analysis and *M* is the mole-fraction of moisture based on dry gas as found by humidity measurements. The mole-fraction m or weight fraction w of moisture in dry air is also found from humidity measurements as explained in the article on "Humidity of Gaseous Mixtures." The calculation of the air $A_w$ lb. or $A_m$ moles actually supplied per unit of fuel will now be explained.

### *Air Actually Supplied for Combustion*

The air actually supplied for combustion may be calculated from analyses of the products of combustion and of the fuel fired. This calculation is based on the fact that the dry products of combustion contain all the dry air supplied for combustion except the oxygen which combined with the hydrogen in the fuel to form moisture. Also, the dry products contain all the fuel except this hydrogen, the moisture in the fuel and the ash with which may be associated more or less unburnt carbon.

For a solid or liquid fuel, the pounds of dry air $A_w$ actually supplied for combustion of one pound of fuel as fired are equal to

$$A_w = P_w + 8\,H - (1 - H - M - R)$$

where $P_w$ is the weight of products per pound of fuel fired, H and M are the weight fractions of hydrogen and moisture in the fuel and R is the weight of refuse (including ash and unburnt carbon) per pound of fuel fired. Expressed in moles, the dry air $A_m$ actually supplied per pound of solid or liquid fuel, is given by

$$A_m = P_m + \frac{H}{4} - \frac{O}{32} - \frac{N}{28} - \frac{CO}{2} \times P_m$$

That is, the moles of dry air are equal to the moles of products plus the moles of oxygen which combined with the hydrogen in the fuel minus the moles of oxygen and nitrogen in the fuel minus one-half the moles of carbon monoxide in the products. The last term is subtracted because each mole of carbon monoxide produced requires only one-half mole of oxygen in the air supplied for combustion, CO representing the volume fraction by analysis of the carbon monoxide in the products which amount to $P_m$ moles per pound of fuel fired.

For a gaseous fuel, the expression for the moles of air supplied per mole of dry gas in the gas as burned is derived from the relations in Table I. Thus, if the volume fractions of the components of a gaseous fuel be represented by the chemical

formulas for these components, then the moles of oxygen which unite with the hydrogen in these components to form moisture in the products of combustion are equal to ($0.5\ H_2 + 0.5\ H_2S + CH_4 + 1.5\ C_2H_6 + C_2H_4$ + etc.) The carbon monoxide $CO$ in the fuel requires only one-half mole of oxygen to form one mole of carbon dioxide in the products. The carbon dioxide $CO_2$, oxygen $O_2$ and nitrogen $N_2$ in the fuel simply augment the dry products of combustion without any corresponding supply of air for combustion. Finally, for each mole of carbon monoxide in the products of combustion, only one-half mole of oxygen has been supplied for combination with the carbon in the components of the fuel, that is, the air actually supplied is less than the moles of products $P_m$ by $1/2\ CO \times P_m$, where CO is the carbon monoxide in the products by analysis. Hence, for a gaseous fuel, the expression for the moles of dry air is

$$A_m = P_m + (0.5\,H_2 + 0.5\,H_2S + CH_4 + 1.5\,C_2H_6 + C_2H_4 + \text{etc.}) - 0.5\,CO - CO_2 - O_2 - N_2 - 0.5\,CO \times P_m$$

The total quantity of moist air actually supplied for combustion is obtained by adding to the number of pounds or number of moles of dry air, the corresponding amount of water vapor determined from humidity measurements as explained in the previous article on "Humidity of Gaseous Mixtures."

### *Combustion Losses*

By comparing the air actually supplied for combustion in any particular case with that theoretically required for complete combustion of the fuel fired, the percentage of "excess air" can be obtained. At the same time, however, the various combustion losses should be calculated as a guide for selecting in future furnace designs, the excess air percentage which will produce the maximum combustion efficiency. These losses are:

(a) Heat not produced by reason of unburnt combustible;
(b) Heat not produced by reason of incomplete combustion of carbon;
(c) Heat discharged from the furnace as latent heat of the moisture formed from the hydrogen in the fuel and originally existing as liquid in the fuel;
(d) Heat discharged from the furnace as sensible heat of the moisture in the products of combustion at the furnace outlet temperature;
(e) Heat discharged from the furnace as sensible heat of the carbon dioxide and sulphur dioxide in the products of combustion at the furnace outlet temperature;
(f) Heat discharged from the furnace as sensible heat of the nitrogen, free oxygen and carbon monoxide in the products of combustion at the furnace outlet temperature;
(g) Losses of heat through the furnace walls and by radiation and conduction from the furnace structure; and
(h) Unaccounted for losses.

TABLE III. PRODUCTS OF COMBUSTION OF ONE MOLE OF GASEOUS FUELS

| Gas | Chemical formula | Carbon dioxide, $CO_2$ mole | Carbon dioxide, $CO_2$ lb. | Moisture, $H_2O$ mole | Moisture, $H_2O$ lb. |
|---|---|---|---|---|---|
| Hydrogen | $H_2$ | .. | ..... | 1.0 | 18.015 |
| Hydrogen sulphide | $H_2S$ | 1.0* | 64.065* | 1.0 | 18.015 |
| Carbon monoxide | $CO$ | 1.0 | 44.000 | .. | ..... |
| Saturated hydrocarbons | | | | | |
| Methane | $CH_4$ | 1.0 | 44.000 | 2.0 | 36.030 |
| Ethane | $C_2H_6$ | 2.0 | 88.000 | 3.0 | 54.045 |
| Propane | $C_3H_8$ | 3.0 | 132.000 | 4.0 | 72.060 |
| Butane | $C_4H_{10}$ | 4.0 | 176.000 | 5.0 | 90.075 |
| Pentane | $C_5H_{12}$ | 5.0 | 220.000 | 6.0 | 108.090 |
| Illuminants | | | | | |
| Ethylene | $C_2H_4$ | 2.0 | 88.000 | 2.0 | 36.030 |
| Propylene | $C_3H_6$ | 3.0 | 132.000 | 3.0 | 54.045 |
| Butylene | $C_4H_8$ | 4.0 | 176.000 | 4.0 | 72.060 |
| Pentylene | $C_5H_{10}$ | 5.0 | 220.000 | 5.0 | 90.075 |
| Acetylene | $C_2H_2$ | 2.0 | 88.000 | 1.0 | 18.015 |
| Benzol | $C_6H_6$ | 6.0 | 264.000 | 3.0 | 54.045 |
| Toluol | $C_7H_8$ | 7.0 | 308.000 | 4.0 | 72.060 |

* $SO_2$

The above grouping of combustion losses has been chosen as representing the most convenient method of calculating them. Other groupings are often used. Thus, items (c) and (d) are generally regrouped to show the combined latent and sensible heat for the several moisture quantities separately, namely, the moisture formed from hydrogen, the moisture in the fuel and the moisture in the air supplied for combustion. Items (e) and (f) are generally considered as one item, namely, the sensible heat in the dry products of combustion. This is convenient when the temperature is low so that sufficiently accurate results are obtained with the same specific heat for all gases involved; but for higher temperatures, these items must be calculated separately, as demonstrated in the article on "Thermal Changes in Gases." Items (g) and (h) are often combined and designated as "radiation and unaccounted for."

Loss (a) is generally calculated for solid fuels containing appreciable quantities of ash under the assumption that the unconsumed combustible in the ashes, clinkers and flue dust is carbon having a heating value of 14,500 B.t.u. per lb., the volatile matter having been distilled off in the furnace. Then,

$$\text{Loss (a)} = 14{,}500\ (C_1R_1 + C_2R_2 + C_3R_3)$$

where $C_1$, $C_2$ and $C_3$ are the weight fractions of combustible in the ashes $R_1$, clinkers $R_2$ and flue dust $R_3$ respectively, each measured in pounds per pound of fuel fired. Often, no attempt is made to determine the weight of flue dust, particularly when coal is burned on the grates of mechanical stokers or of hand-fired furnaces. With very high rates of combustion, this results in a high unaccounted for loss. For liquid and gaseous fuels producing practically no ashes or clinkers, this loss is generally ignored. Any attempt to calculate it must be based on the analyses of the flue gases and of the fuel for the particular case under consideration.

Loss (b) is evidently equal to 121,700 B.t.u. per mole of CO in the products of combustion as indicated by the combustion reaction for carbon monoxide in Table I. Hence, if $P_m$ denote the moles of products per pound of solid or liquid fuel or per mole of gaseous fuel, we have

$$\text{Loss (b)} = 121{,}700 \times CO \times P_m$$

where CO is the volume fraction of this constitu-

ent of the products of combustion. Since for solid and liquid fuels,

$$P_m = \frac{C_B + \frac{3}{8} S}{12\,(CO_2 + CO)}$$

we have for these fuels,

$$\text{Loss (b)} = 10140 \frac{CO}{CO_2 + CO} (C_B + \frac{3}{8} S)$$

Loss (c) for a room temperature of 70 fahr. may be taken for solid and liquid fuels as

$$\text{Loss (c)} = 1050\, [9\, H + M]$$

in accordance with the discussion on the apparent latent heat of water vapor in the article on "Humidity of Gaseous Mixtures. Here H and M represent the weight fractions of hydrogen and moisture respectively in the fuel as fired. For gaseous fuels this loss is 18900 B.t.u. per mole of $H_2O$ produced by the combustion of the hydrogen in the fuel gas. Hence, for one mole of dry fuel gas,

$$\text{Loss (c)} = 18900\, [H_2 + H_2S + 2CH_4 + 3C_2H_6 + 2C_2H_4 + \text{etc.}]$$

where $H_2$, $H_2S$, $CH_4$ etc., represent the volume fractions of these constituents of the fuel.

Losses (d), (e) and (f) may all be calculated by using the table of sensible heats of these gases given in the article on "Thermal Changes in Gases." From the tabular value of sensible heat for the temperature at which the products are discharged into the atmosphere is subtracted the tabular value of the sensible heat for room temperature, say 70 fahr. This difference is then multiplied by the moles of products per pound of solid or liquid fuel or per mole of gaseous fuel.

Loss (g) is calculated from the dimensions of the furnace, kind and thickness of insulation, etc.

Loss (h) is found by difference between the heating value of the fuel and the sum of the usefully applied heat and losses (e) to (g).

*Approximate Combustion Relations*

In addition to the above exact relations, certain approximate relations are useful in combustion calculations for quickly judging the performance of a given furnace. Thus, neglecting the nitrogen in the fuel, the moles of dry atmospheric air supplied for combustion are given by

$$A_m = \frac{N_2}{0.79} P_m$$

where $P_m$ are the moles of products and $N_2$ is the volume fraction of nitrogen in the products. This approximate relation cannot be applied to blast furnace gas, producer gas and certain natural gases by reason of the high percentages of nitrogen present in the fuel. For solid and liquid fuels, this expression may be reduced to

$$A_w = 28.966\, A_m = 28.966 \frac{N_2}{0.79} \frac{C_B + \frac{3}{8} S}{12(CO_2 + CO)}$$

$$= 3.055 \frac{N_2}{CO_2 + CO} (C_B + \frac{3}{8} S)$$

The percentage of excess air supplied for combustion may be calculated approximately when the unburnt carbon loss is small from the analysis of the products of combustion of fuels containing but little nitrogen. Thus, the nitrogen present in the products is a measure of the total air supplied for combustion while the free oxygen is a measure of the excess air. For every mole of carbon monoxide in the products, there is present one-half mole of free oxygen which would not have been there if the combustion had been complete. Hence, the true moles of excess oxygen per mole of dry products are $(O_2 - CO/2)$. Therefore

$$\text{Excess air fraction} = \frac{0.79}{0.21} \frac{O_2 - CO/2}{N_2}$$

TABLE IV. COMBUSTION FORMULAS

| | Pounds per pound of solid or liquid fuel | Moles per pound of solid or liquid fuel | Moles per mole of dry gaseous fuel |
|---|---|---|---|
| Dry air theoretically required for complete combustion. | $\frac{2.67\, C + 8\,(H - \frac{O}{8}) + S}{0.232}$ | $\frac{\frac{C}{12} + \frac{H}{4} + \frac{S}{32} - \frac{O}{32}}{0.21}$ | $\frac{(0.5\, H_2 + 1.5\, H_2S + 0.5\, CO + 2\, CH_4 + 3.5\, C_2H_6 + 3\, C_2H_4 + \text{etc.})}{0.21}$ |
| Dry products of combustion. | $\frac{(11\, CO_2 + 7\, CO + 8\, O_2 + 7.04\, N_2) \times (C_B + \frac{3}{8} S)}{3\,(CO_2 + CO)}$ | $\frac{C_B + \frac{3}{8} S}{12\,(CO_2 + CO)}$ | $\frac{(CO_2 + CO + H_2S + CH_4 + 2\, C_2H_6 + 2\, C_2H_4 + \text{etc.})}{(CO_2 + CO)}$ |
| Moisture in products of combustion. | $w\, A_w + M + 9\, H$ | $m\, A_m + \frac{M}{18} + \frac{H}{2}$ | $m\, A_m + M + H_2 + H_2S + 2\, CH_4 + 3\, C_2H_6 + 2\, C_2H_4 + \text{etc.}$ |
| Dry air actually supplied for combustion. | $P_w + 8\, H - (1 - H - M - R)$ | $P_m + \frac{H}{4} - \frac{O}{32} - \frac{N}{28} - \frac{CO}{2} \times P_m$ | $P_m + (0.5\, H_2 + 0.5\, H_2S + CH_4 + 1.5\, C_2H_6 + C_2H_4 + \text{etc.}) - 0.5\, CO - CO_2 - O_2 - N_2 - 0.5\, CO \times P_m$ |
| Moisture in air supplied for combustion. | $w\, A_w$ | $m\, A_m$ | $m\, A_m$ |

C, H, S, N, O, M, weight fractions of carbon, hydrogen, sulphur, nitrogen, oxygen and moisture in solid or ilquid fuel by analysis.

$CO_2$, $O_2$, $CO$, $N_2$, $H_2S$, $CH_4$, $C_2H_6$, $C_2H_4$, etc., volume fractions of these constituents of a gaseous fuel by analysis. $M$ moles of moisture per mole of dry gaseous fuel.

$CO_2$, $O_4$, CO, $N_2$ volume fractions of products of combustion by analysis.

$C_B$ lb. carbon burned, R lb. refuse formed, $A_w$ lb. dry air supplied, $P_w$ lb. dry products produced per lb. of solid or liquid fuel, $A_m$ moles dry air supplied, $P_m$ moles dry products produced per lb. of solid or liquid fuel.

$A_m$ moles of dry air supplied, $P_m$ moles of dry products produced per mole of dry gaseous fuel.

w lb. moisture per lb. of dry air, m moles of moisture per mole of dry air.

where $O_2$, CO, and $N_2$ are the volume fractions of these constituents in the products. It is incorrect to add one-half carbon monoxide to the oxygen as is sometimes done.

Often, the carbon dioxide percentage only in the products of combustion is known. In such cases, as pointed out by E. A. Ferris of Combustion Engineering Corporation, the volume fraction of oxygen in the products can be calculated approximately from the analysis of the fuel by means of the relation

$$O_2 = 0.21 - CO_2 \left(1 + 2.37 \frac{H}{C}\right)$$

where $CO_2$ is the volume fraction of carbon dioxide in the products and C and H are the weight fractions of carbon and hydrogen in the fuel. This approximate relation is obtained from the exact relation

$$O_2 = 0.21 - CO_2 - 0.605\ CO - \frac{12\,(CO_2 + CO)}{C_B + \frac{3}{8} S} \left[ 0.79 \frac{H}{4} + 0.21 \frac{N}{28} - 0.79 \frac{O}{32} \right]$$

by neglecting the carbon monoxide CO in the products of combustion and the sulphur S, nitrogen N and oxygen O in the fuel, and taking the carbon $C_B$ burned as the total carbon C in the fuel. The latter expression is derived from the relations

$$\frac{C_B}{12} + \frac{S}{32} + O_2 \times P_m + N_2 \times P_m = P_m$$

$$\frac{CO_2 \times P_m + \frac{CO}{2} \times P_m + \frac{H}{4} + O_2 \times P_m - \frac{O}{32}}{N_2 \times P_m - \frac{N}{28}} = \frac{0.21}{0.79}$$

$$P_m = \frac{\frac{C_B}{12} + \frac{S}{32}}{CO_2 + CO}$$

If we solve the approximate expression above for carbon dioxide with no free oxygen, we get the maximum possible volume fraction of carbon dioxide in the products of combustion, namely,

$$CO_2 = \frac{0.21}{1 + 2.37 \frac{H}{C}}$$

*Summary*

In Table IV are summarized the various relations of use in calculating the dry air theoretically required for complete combustion of any fuel of known analysis, also, the relations for determining the air actually supplied and the products produced in any furnace where the analysis of the products of combustion is known. These quantities serve as the basis for preparing a combustion heat balance for the furnace in question which may be for one pound of dry solid or liquid fuel but preferably for the fuel as fired. For gaseous fuels, the quantities are most conveniently calculated for one mole of dry gaseous fuel and then reduced to one cubic foot of gas as fired by dividing by the volume of one mole of dry gas in the gas as fired under the specified conditions as to pressure, temperature and humidity.

*References*

The Power Test Codes of the American Society of Mechanical Engineers, particularly the Test Code for Stationary Steam Boilers, are of interest in this connection. Mention should also be made of the Industrial Gas Series of the American Gas Association, particularly the booklet on Combustion. The subject is also treated more or less fully in the various handbooks on combustion and steam generation and in textbooks on power engineering and thermodynamics.

## The Physical Characteristics of Natural Draft Chimneys

(*Continued from page 20*)

fact that high temperatures drive out the water of dehydration with the result that the concrete tends to crumble; inherent tendency to develop cracks due to intensity of stresses or insufficiency of reinforcement around the breeching opening, (this can be reduced to a minimum by proper placing of the extra reinforcement as noted); appearance out of harmony with brick buildings; constant danger from an initially poor section of concrete endangering the stability of the entire structure. (this possibility is practically limited to cold weather construction and can be prevented by eternal vigilance and proper heating of materials during the pouring and proper protection afterwards until the concrete has set); impossible to alter in any manner except at great expense; practical indestructibility of the entire structure involving great expense if necessary to wreck.

It should be noted in particular that the disadvantages given for the various types of chimneys are relative only and are based on facts which are the result of experience. They are not sales arguments to be used against the types which a correct analysis would indicate to be unsuitable for a particular installation but rather as considerations which will aid in the selection of the most suitable type. No one type of chimney construction has any preponderating advantage over the others, but each type is especially adaptable to certain installations and, generally speaking, the disadvantages noted for a certain type pertain to installations for which that type is not especially adapted. As a general rule, however, the selection of the type of chimney is a matter of choice of the purchaser. In making such a choice, the purchaser should be guided not so much by cost as by the factors of adaptibility, feasibility and practicability.

# Removal of Moisture from Steam

By C. E. JOOS
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**The importance of dry steam in power plant operation is quite generally realized. Nevertheless, there are many plants which are not taking proper advantage of the means and methods available for assuring practically moisture-free steam. The author indicates the various causes of wet steam and discusses the methods of moisture removal which are used in present-day practice. He favors the use of the external type of steam purifier or separator preferably in combination with a blowoff system or so arranged that it also performs the function of blowoff.**

FOR the most economical operation of superheaters, turbines, engines, desuperheaters, etc., pure, dry steam is essential. Moisture in steam, accompanied by dirt, alkali, and grit, not only decreases the normal power that might be expected from dry steam but also causes wear and tear on moving parts, resulting in abnormal maintenance costs. The effects of very wet steam on a superheater tube are illustrated in Fig. 2, which shows a section of a tube removed from a superheater in which a number of tubes had become completely clogged up with dirt carried by the saturated steam, causing rupture and necessitating shutting down for repairs. The plant in which this occurred was troubled with such severe priming and foaming that after only four days' operation a number of superheater tubes would invariably become plugged up with deposit as indicated in Fig. 2. This case is, of course, exceptional but illustrates the damage that may be caused by excessive moisture in the steam. The trouble has since been corrected by the installation of efficient steam purifiers of the external type to remove the moisture from the saturated steam before delivery to the superheaters. Fig. 6 shows the condition of the concentrated boiler water, steam purifier discharge and purified steam after the installation of the steam purifier, indicating the quantities of dirt that may be carried over with saturated steam.

Another instance of the effects of dirty steam is to be seen in Fig. 3 which shows a brass valve seat which has been damaged by erosion and corrosion due to alkali and dirt. Erosion of brass valve parts is greatly accentuated by caustic soda, which is present in all boiler waters receiving chemical treatment. The damage due to wet steam extends through the superheater to the turbine; Figs. 1 and 4 show how dirt clogs the blades of turbines, as well as the effect of impure steam in wearing away of the metal. Pure, dry steam would not have given rise to either of the conditions illustrated.

In many cases wet steam delivered to a superheater does not result in a deposit, but the moisture is simply evaporated in the superheater and the dirt and solids are carried along and act as a sand blast in the turbine.

The destruction to apparatus by dirty steam not only causes excessively high maintenance, but also results in inefficient operation. For instance, Fig. 5 shows the effect of superheat on the turbine water rate, and since superheat is reduced by moisture in the steam, as indicated in Fig. 7, it indicates to what degree the steam economy will be impaired with a turbine of the characteristics indicated. Suppose, for instance, a 15,000 kw. turbine has the water rate characteristic shown. With steam at 250 lb. pressure, and 200 deg. fahr. superheat, the presence of two per cent moisture in the steam entering the superheater would reduce the superheat by 33 deg. fahr. and increase the water rate from 10.75 lb. per kw. to 11 lb. per kw., which in a year would amount to a loss of nearly $1300, on the basis of using $5.00 coal, 14,000 B.t.u. per pound, 80 per cent boiler efficiency and 300 deg. fahr. feed water temperature.

The bad effects of wet steam or desuperheated steam as a result of moisture are also felt with reciprocating engines, but here another difficulty arises, namely, the inability to lubricate wet surfaces efficiently and economically. Water in steam washes oil off cylinder and valve surfaces and makes necessary the use of a more expensive compounded oil which will adhere to wetted surfaces.

### *Causes of Wet Steam*

A universal cause of wet steam cannot be found

Fig. 1—Deposits on turbine guide vanes from dirty steam

Fig. 2—Cross section of superheater tube showing complete clogging due to impurities in steam

Fig. 3—Valve eroded by wet steam

Fig. 4—Turbine blades eroded and scaled by impure steam

which applies to every individual plant, as the causes may be many and varied depending upon individual conditions. Generally speaking, however, the following may be listed as the more important factors which enter into the priming, foaming or moisture entrainment problem:

1.—Design of boiler, with particular reference to the size of the steam liberating drum as compared with the rate of steam delivery.
2.—Rating at which the boiler is operated.
3.—Characteristics of the load.
4.—Height of water in the steam drum.
5.—Characteristics of feed water supply which from the standpoint of causing foaming and priming may be considered as follows:
   (A)—Degree of concentration of soluble solids.
   (B)—Degree of alkalinity.
   (C)—Amount of suspended matter present.
   (D)—Amount and kind of organic matter, such as oils and possibly tannins.

Boiler manufacturers are giving increasing attention to the design of boilers particularly with reference to the ratio of output to steam storage space and to liberating surface. The necessity of improving the quality of steam delivered by boilers has been emphasized by the rather wide use of high rating boilers.

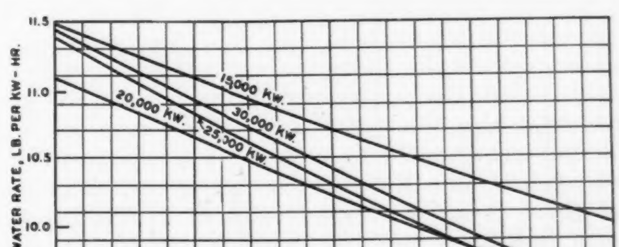



Fig. 5—Effect of superheat on turbine water rate

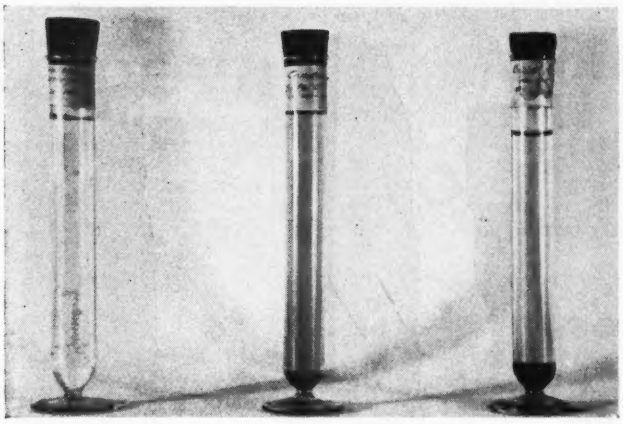


**Fig. 6—Samples (left to right) of condensed steam after purifier, condensed steam before purifier and boiler water.**

The relation between moisture in the delivered steam and the rate of steam generation per cubic foot of steam space is given in Fig. 8. This chart* is based upon the concentration of soluble salts not being over 100 grains per gallon of the boiler water. The author states that the amount of moisture in steam may nearly double for each 100 grains per gallon above 100 grains per gallon and that the feed water should not contain any chemicals or organic matter. It would appear from this curve that the higher the rating the greater the tendency to deliver wet steam.

The higher the rating at which the boiler is operated, the greater will be the tendency for foaming and priming or entrainment of moisture, even if the concentration of boiler water salts is very low. For instance, in a number of plants using evaporated make-up, the content of moisture in the steam at high rates of driving is relatively great. This moisture content will be aggravated by the maintenance of high water level, as well as by a rapidly fluctuating load. The fluctuating load problem is accentuated with boilers operating with flexible fuel, such as oil, gas or pulverized fuel.

With these fuels, it is easy to increase the load materially on a moment's notice and, conversely, to drop the load in a very short space of time. Such fluctuations in load cause a rapidly fluctuating water level within the drum, changing the liberating surface and the steam storage space and adding to the general moisture entrainment problem. In this connection Prof. A. G. Christie states, "A new phenomena has developed with large modern boilers having entirely water-cooled furnaces that absorb great quantities of radiant heat. When these boilers are operated at high ratings, a large portion of the tube volume is occupied by the bubbles of steam that have been generated on the radiant heat absorbing surfaces. If a heavy load is suddenly removed from such a boiler burning pulverized fuel, the flame is virtually extinguished and there is no further source of radiant heat; steam bubbles cease to form; water then flows from the drum, to fill the tube volume formerly occupied by the steam bubbles, at such a rapid rate that the water level may disappear entirely from the gage glass. In fact in certain boilers all the water in the drum may be withdrawn under these conditions and the circulation be momentarily destroyed. As soon as the load comes on and steam bubbles are again formed in the tubes, the normal water level will be restored. During the outage the feed water regulator will endeavor to restore the normal water level by admitting additional feed water. If a heavy load is again added there will be an excess of water in the drum, which probably will cause water slugs or wet steam to be delivered to the superheater, disturbing superheat."

Regarding this problem Geo. A. Orrok, in his paper, "High Pressure Steam Boilers" states, "In most modern boilers less than 15 per cent of the water is contained in the drum and when steaming at a high rate more than 20 per cent by volume of the water is steam bubbles." This condition of operation will lead to wet steam troubles unless precautions are taken for removing the water.

Steam contamination resulting from chemical causes may also be accentuated by the character of feed water supply. Where the feed water contains much suspended matter or an unduly large quantity of soluble salts, the degree of steam contamination will be increased. Contamination of feed water by oil, particularly compounded oils, may result in foaming tendencies when the water is treated chemically.

Professor C. W. Foulk's paper, "Foaming of Boiler Water" is perhaps the best discussion of this subject ever presented and is backed up by laboratory experiments. Prof. Foulk has found that the presence of both a relatively high concentration of sodium salts and a large amount of suspended matter is essential to foaming, and within the limits of accuracy of his experiments, both suspended solids and soluble solids have about the same ef-

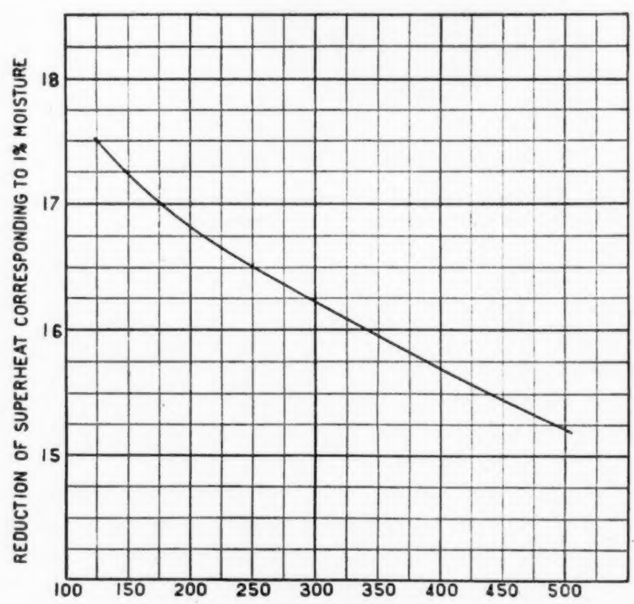



**Fig. 7—Reduction of superheat due to 1 per cent of moisture at different pressures.**

* Relative Moisture in Steam from Boiler, by J. Gould Countant.

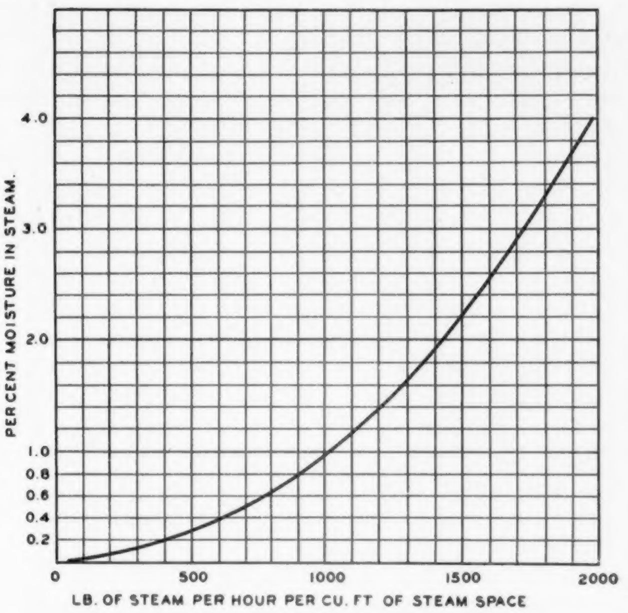



**Fig. 8—Rlation between moisture in delivered steam and rate of steam generation per cubic foot of steam space.**

fect. The higher the concentration of sodium salts, the lower must be the suspended matter to prevent priming, and likewise the lower the concentration of sodium salts, the higher may be the suspended matter without foaming.

Dr. R. E. Hall in his paper, "Present Tendencies of Boiler Water Conditioning" attacks steam contamination from a somewhat different angle. He points out the desirability of maintaining a few parts per million of calcium hydroxide in the water for stabilizing the films of the bursting steam bubbles. However, with a properly treated water this cannot be maintained. He also states that the addition of two or three parts per million of an oil such as castor, or other organic oils such as sperm or fish oil, can exercise a tremendous influence in lessening the stability of films and in inducing in a foaming water conditions which are comparable to those of distilled boiler water. While a number of further suggestions have been made for diminishing foaming in boiler water, the conclusion is reached that none of these methods for quieting foaming are available in practical operation.

### *The Production of Clean, Dry Steam*

The solution of foaming and priming or entrainment problems, independently of what the cause may be, can be had through the use of steam purifiers or steam separators. While steam purifiers or separators do not by any means correct the source of the trouble, they do prevent damage from moisture. In the modern plant, the steam purifier is interposed in the saturated steam line between the boiler outlet and the superheater inlet. An efficient steam purifier in this location affords complete protection to superheaters, steam lines, turbines, condensers, etc. The engineering public has been educated along these lines for a number of years and various devices have been offered.

Steam purifiers as first proposed were installed within the steam drum and undoubtedly served their purpose fairly well under conditions of low ratings and ample steam space within the drum. However, when boilers were operated under fluctuating loads and at high ratings, when every bit of steam space within the steam drum is desirable for initial separation of the moisture from the steam, these devices did not function so satisfactorily. For correcting excessive steam contamination, it became quite evident that the steam purifier should not detract from the space within the steam drum, which already was too small, especially in high pressure boilers.

The general tendency today, therefore, is to have steam purifiers external to boilers. Such purifiers have drums shaped similarly to boiler drums, although not quite so long. The diameter, generally speaking, is about the same as that of the boiler drum which they serve. The results of purifying steam external to the boiler have been most satisfactory, perfect protection being afforded to equipments otherwise subject to damage by moisture.

Fig. 9 illustrates a modern, high-rating 650 lb.-pressure boiler fitted with an external type of steam purifier. It should be noted that at this plant a steam purifier is provided for obtaining dry steam, even though the makeup is put through evaporators and the concentration of solids within the boiler is never very high.

Central stations using evaporated makeup also find steam purifiers beneficial in purifying the evaporator vapor. The contamination of the evaporator vapor would otherwise be carried over to

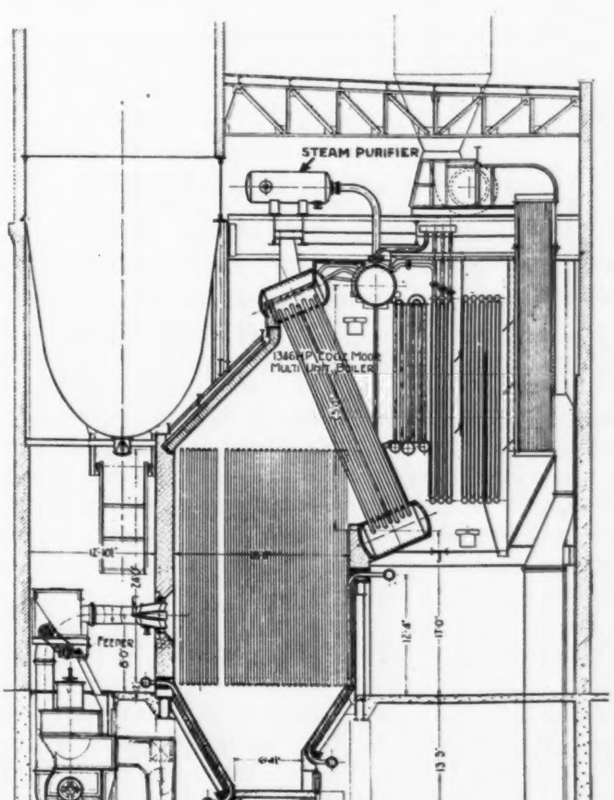



**Fig. 9—Steam purifier in connection with high pressure boiler in a paper mill.**

the feedwater and thence to the boiler, increasing the solids, hence the tendency to priming; or, putting it another way, if the steam contained moisture, the increased solids in the boiler water would bring about a greater likelihood of deposits. In one plant, the use of steam purifiers on evaporators

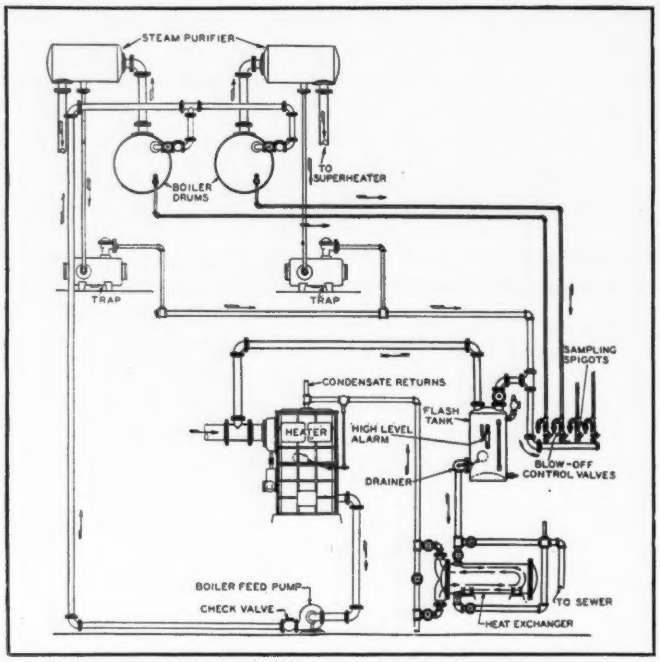



**Fig. 10—Arrangement drawing showing use of continuous blowdown in conjunction with steam purifiers**

reduced the content of solids in the evaporated makeup from 2.0 p.p.m. to 0.2 p.p.m.

Other means of producing dry steam are employed, such as the use of continuous blowoff equipment. Such measures attack the steam contamination from the direction of the soluble solids in the boiler water only. While, in a great many cases, continuous blowoff equipment has materially improved steaming conditions, it cannot give as positive a guarantee of dry steam, as can the installation of an external steam purifier. One design of continuous blowoff system employed for this purpose is illustrated in Fig. 10. This shows the utilization of heat from the blowdown by flashing and using flashed steam to supplement exhaust and transferring remaining heat to cold feed water by a heat exchanger. Blowoff equipments have the advantage that the concentration of solids within the boiler may be held very low without an excessive wastage of heat, a condition essential to economical plant operation.

Where the steam purifier is coupled with the continuous blow-off system, we have the ideal solution of the wet steam problem, giving perfect assurance of clean dry steam with minimum heat loss. With certain kinds of steam purifiers, as that illustrated in Fig. 9, this condition can be brought about. A steam purifier of the external type, with sufficient capacity for removing slugs of water, can be operated successfully where the blowoff from the boiler is entirely through the steam line in the form of priming, that is, in operating with a steam purifier of this type, the regular blowoff valves need never be used. The concentration builds up to a point where any increase results in wet steam. The steam is stripped of this moisture in its passage through the purifier and the heat of the moisture thus removed is recovered in a suitable heat exchanger apparatus, as for instance, by flashing the trap discharges to the feedwater heater, using the flashed steam to supplement the exhaust, and recovering the remaining heat of the liquid by transferring it in heat exchangers to the cold makeup water. Fig. 11 shows the results of a test conducted on a steam purifier operated as a continuous blowdown. Even though the average moisture content of the saturated steam was in excess of 5 per cent, the purified steam averaged 0.11 per cent which is within the limit of accuracy of a throttling calorimeter, this limit being generally considered as 0.2 per cent.

Installations operating along these lines have been in successful use for a sufficiently long time to demonstrate the practicability of continuing the desirable features of the continuous blowoff system with the assurance which purifiers give that the steam will at all times be dry. This method of controlling the blowdown through steam purifiers is entirely automatic and operates at maximum efficiency at all times, since the amount of water blown down represents the quantity that must be relieved to meet the conditions as to maximum concentration under which the boiler can be operated. To insure dry steam with ordinary, continuous-blowoff arrangements but without steam purifiers, more water would have to be removed from the boiler in order to provide a margin of safety for the delivery of reasonably dry steam.

The objection to the use of this method is the severe duty placed upon the traps. This objection is easily overcome by operating a continuous blow-

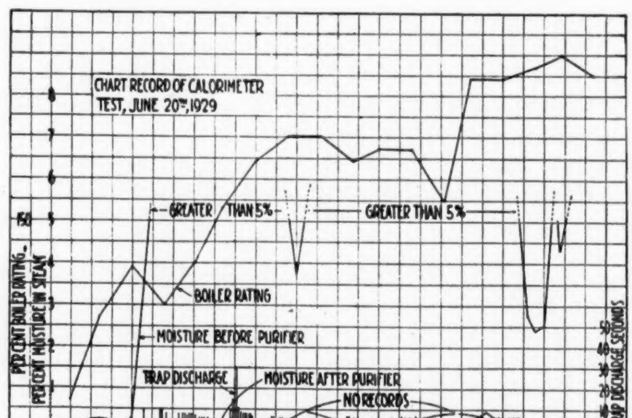
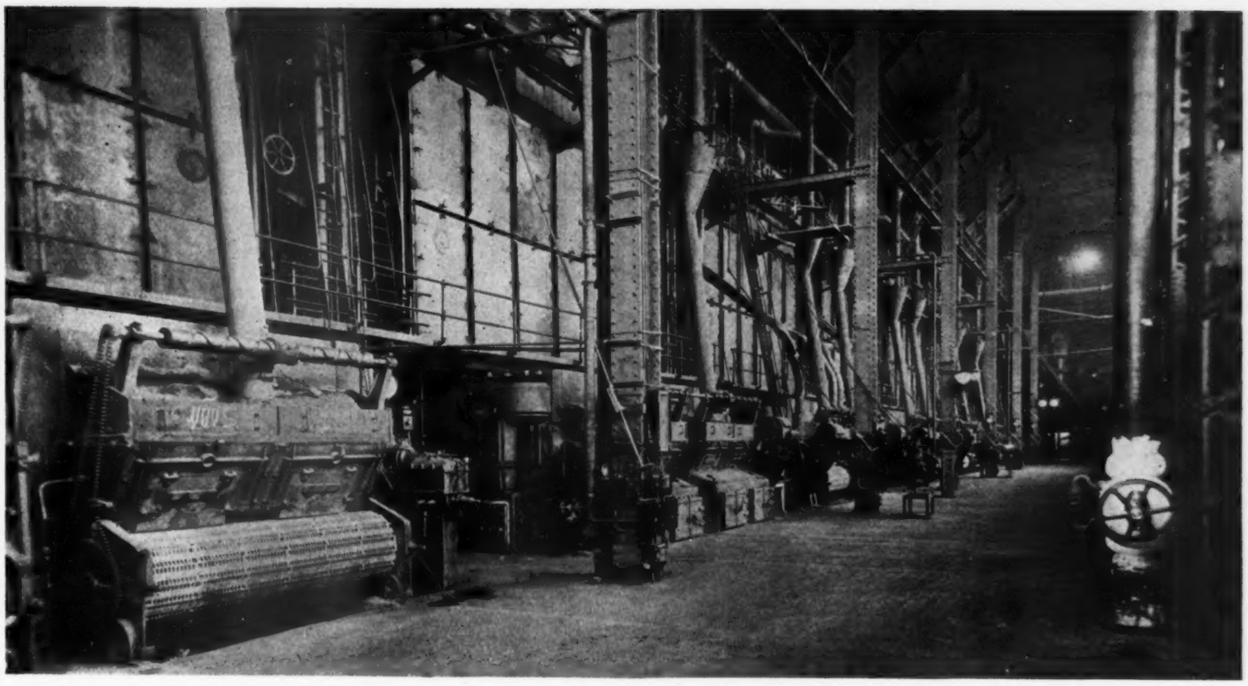



**Fig. 11—Record of test on steam purifier used as continuous blow-off**

down in conjunction with steam purifiers as illustrated by Fig. 10. By this method the continuous blowdown is so operated that the concentrations are of an order which assures the purifiers removing moisture that may be caused by variable operating conditions.



No. 1 Boiler House, Barking Station

# The Barking Power Station, London

## A Description of the Present Plant and the New Extension Now Under Construction

### By DAVID BROWNLIE, London

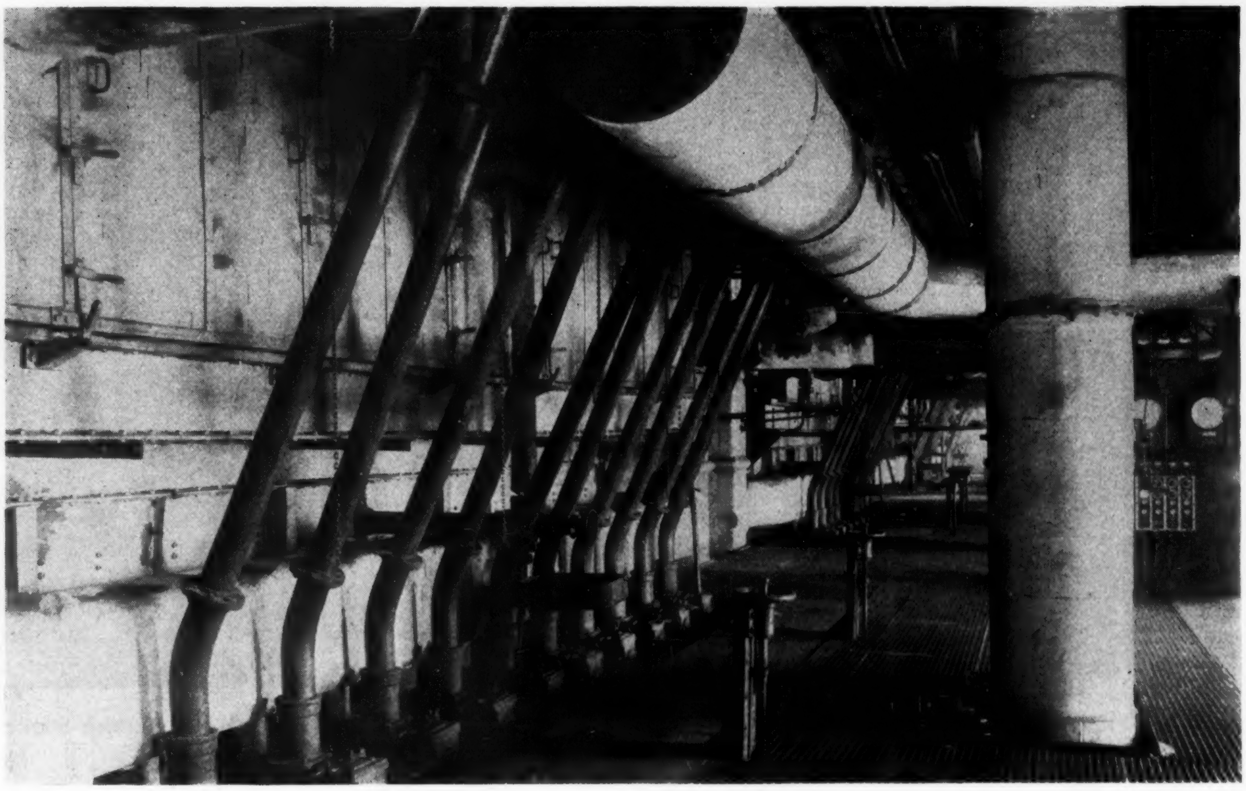
**The Barking Power Station is now constructing a 150,000 kw. extension which will bring its total capacity up to 390,000 kw. A further 150,000 kw. extension is planned for the future. Mr. Brownlie describes the equipment comprising the two existing sections of this important station as well as the equipment to comprise the extension now under construction and to be completed in 1932. While the developments of the period have been fully considered as each extension was made, the general design has been along conservative lines.**

At the present time, the largest and most important power station in Great Britain is the Barking plant of the County of London Electric Supply Co., Ltd., situated on the north bank of the River Thames, below all the bridges, and with a half-a-mile water front. The total site, to the east of a point where Barking Creek joins the Thames, is about 50 acres, with ample cooling water and deep water accommodation for ocean-going coal ships.

Two sections, each of 120,000 kw., or a total of 240,000 kw. comprise the existing plant, but contracts have recently been placed for the immediate erection of a third section of 150,000 kw., which is to be in operation by the winter of 1932, and which will increase the capacity to 390,000 kw. There will also be a later 150,000 kw. extension, bringing the total capacity up to 540,000 kw.

The equipment comprising the first two sections will be described first in order to provide a background for a consideration of the new extension.

The construction of the Barking Station was begun in 1923, the first generating unit having been put into service at the end of 1924, but the official opening did not take place until May 19, 1925. At the present time, as already indicated, two sections are in operation, the first of which comprises No. 1 Boiler House with turbo-generators Nos. 1, 2, 3, and 4, half of the present jetty, pump house and coaling equipment this work being finally completed in 1927. After this, there was constructed the second section consisting of No. 2. Boiler House and turbo-generators Nos. 5, 6, 7 and 8, as well as the rest of the jetty, pump house,



View of pulverized-fuel boilers at burner level

and coaling plant, completed in the early part of 1930 each of these sections being 120,000 kw.

Thus, the present Barking Station consists of the turbine room with two boiler houses at right angles, forming one group, while the switch house, control room, and office accommodation constitute a separate building, connected to the turbine room by a bridge. The whole installation, along with the various accessory buildings and office accommodations, is supported on reinforced concrete piles, each 14 in. square, capable of carrying 50 tons, driven down into the ballast. Also the boiler house is of reinforced concrete, with the bottom floor level 19 ft. 5 in. below the ordnance datum, so that the pump suctions are always drowned at every stage of the tide from the River Thames. The pumping equipment consists of 9 pumps each of 24,000 gal. per min. capacity, driven by a 430 hp. motor, and 3 pumps of 9,000 gal. per min. capacity, driven by a 168 hp. motor. Half of these are Allen pumps with Metro-Vick motors, and the other half Drysdale pumps with English-Electric motors, all delivering against a static head of 37 ft.

The main coaling jetty is 460 ft. long, and arranged for both barges and ocean-going steamers up to 5000 tons capacity, while it is possible to accommodate steamships up to 8000 tons if further dredging is done. Although sea-borne coal is normally used, there is also rail connection to the London and Tilbury section of the London, Midland and Scottish Railway.

On the jetty are four cranes, each of which discharges coal from vessels at the rate of 100 tons per hour and up to 200 tons maximum, with belt conveyors discharging to a storage ground, between the jetty and the boiler house, of 30,000 tons capacity, gravity bucket conveyors connecting the belt system to the boiler house bunkers. The reserve coal storage capacity is 120,000 tons.

The ordinary coal storage or running coal stock is served by a belt conveyor having four belts, with a total of 400 tons of coal per hour capacity. For the coal storage handling, there are two traveling bridges, each of 197 ft. 6 in. span and 20 ft. ground clearance, while each boiler house has two overhead coal bunkers.

No. 1 Boiler house has 12 boilers and 4 combined steam reheater and boiler units, but two of the latter are operating only as ordinary boilers, that is without reheating. The operating conditions are 375 lb. per sq. in. pressure and a steam temperature of 725 deg. fahr. with feedwater at 250 deg. fahr. Six of the boilers and two of the completed reheater units are of B. & W. manufacture, the other eight boilers being of Yarrow manufacture. Each boiler and reheater boiler unit is equipped with a superheater and an air preheater, but no feedwater economizer, and is operated separately with its own mechanical forced and induced draft fans. The two completed reheater boiler units are run in conjunction with No. 1 turbo-generator. Each boiler, except the two Yarrow incomplete reheaters, has spring-loaded safety valves of Cockburn design and boiler mountings of Hopkinson and Dewrance construction.

Each of the B. & W. boilers has a normal evaporation of 68,000 lb. of water per hour, with an overload of 85,000 lb. having a heating surface of 12,028 sq. ft., a superheater surface of 2309 sq. ft., and an air preheater surface of 17,000 sq. ft. The

boilers are of the cross-drum type with vertical headers. The air preheaters are of the tubular type, reducing the final temperature of the flue gases to about 325 deg. fahr. Cope's feedwater regulators are used. The chain grate stokers, two per boiler, are of B. & W. make, each 9 ft. wide and 16 ft. long, with a total grate area of 288 sq. ft.

The six main Yarrow boilers each have an evaporation of 68,000 lb. per hr. and a heating surface of 11,700 sq. ft., with 2600 sq. ft. superheater surface and 17,000 sq. ft. air preheater surface. Each boiler has two Underfeed Type L traveling grate stokers 9 ft. 8 in. wide by 17 ft. 6 in. long, providing a total grate area of 332.5 sq. ft. The air preheaters for these units also are of tubular design, reducing the flue gases to 325 deg. fahr. Crosby feedwater regulators are used.

The two B. & W. combined boilers and reheaters each have a heating surface of 6840 sq. ft., a superheater surface of 1680 sq. ft., and an air preheater surface of 17,000 sq. ft., the reheater steam heating surface being 14,000 sq. ft. They are operated with two B. & W. chain grate stokers of the same size as the other B.&W. stokers. The duty is a normal evaporation of 44,000 lb. of steam per hour, together with the reheating of 165,000 lb. of steam per hour from 350/450 deg. fahr. to 725 deg. fahr.

The fan equipment for both sets of boilers consists of Sirocco induced and forced draft fans supplied by Davidson & Co., Ltd., of Belfast, the induced draft fan for each boiler being of 53,550 cu. ft. per min. normal capacity, and 74,800 cu. ft. overload, (325 to 400 deg. fahr.) and the forced draft fan of 34,100 cu. ft. per min. normal capacity and 44,500 cu. ft. overload (70 deg. fahr.).

For the first section, therefore, completed in 1926, the chief points are comparatively small boilers, both of B. & W. and Yarrow make, low steam pressure, and moderately superheated steam temperature with traveling grate stokers and air preheaters, no economizers, and experimental reheating.

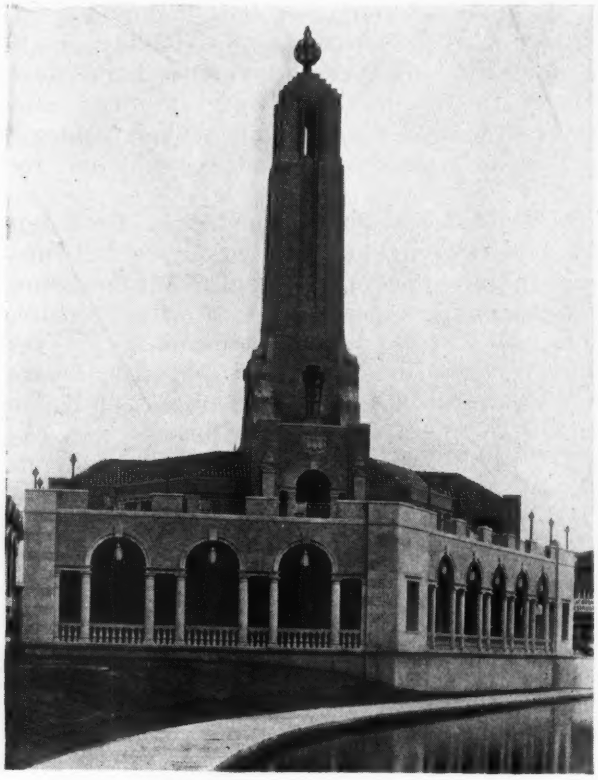
In the second section, completed in 1930, ten B. & W. boilers are installed, of larger size but running under the same conditions of 375 lb. pressure and 725 deg. fahr. superheated steam temperature, and equipped with the Lopulco bin-and-feeder system of pulverized fuel firing, as supplied by International Combustion, Ltd., of London. Each boiler has 16,510 sq. ft. of heating surface, a rated capacity of 135,000 lb. of steam per hour and an overload of 187,500 lb. The superheaters have a heating surface of 4300 sq. ft.; the feedwater economizers, 6000 sq. ft.; and the air preheaters, 19,920 sq. ft. The furnaces are equipped with Murray water-cooled walls of 1320 sq. ft. heating surface comprising both side and rear walls as well as a water screen of 470 sq. ft. of surface. The furnace volume is 11,450 cu. ft. Vertical firing is used, each furnace being equipped with 10 fishtail burners.

These ten boilers are arranged in two rows along the length of the boiler room. There are also two separate rows of overhead coal bunkers from which the coal is discharged to the pulverizing mills below. Five short steel chimneys serve these units, one chimney for two boilers.

Superheaters are of the M.L.S. type, feedwater economizers of the Foster type with single gas

(*Continued on page 50*)

**General view of turbine room**



# New Asbury Park Steam Plant Combines Utility with Beauty

By A. W. PATTERSON, Jr.
Vice President
The Engineer Company, New York

IN the midst of many striking and pretentious buildings at Asbury Park, New Jersey, is a monumental structure, the main portion of which is a pavilion surmounted by a broad terrace that overlooks the gaiety of the city and the sweep of the bordering sea. Rising from the center of this structure is what appears to be a tower, splendidly proportioned,—an architectural masterpiece. Its top is an open cupola upon which rests a globe of metal and glass containing a beacon light. At the face of this tower, immediately below the cupola, is a "witches' caldron" which, at night, by the aid of a cloud of steam and an ingenious lighting arrangement, has the appearance of emitting flames.

The entire structure including the commanding tower is finished in resplendent white that glitters in the sun by day and presents chiselled outlines and sharply defined shadows when beams of light are poured upon it at night. This structure is part of a group that includes a casino, three pavilions, a bath house and a large theatre, all belonging to the municipality of Asbury Park and part of an architectural ensemble so perfectly designed and executed that they represent the most notable group of the kind on the New Jersey coast. This structure is distinctly a thing of beauty—an ornament to a famous resort city that is striving for an esthetic reputation as one of the most effective means of gaining and holding the attention and patronage of the public. Nevertheless, this building is a steam plant; the housing place of boilers and furnaces. The tower is the chimney. The sole purpose of the plant is to produce steam for the reliable and economical production of heat to serve the many buildings for a mile around which demand heat, for at least a portion of the day, throughout nearly the entire year. The usefulness of the legion of shops, stores and amusement places, as well as the great swimming pool and large auditorium, is dependent upon heat to insure the comfort of their patrons, for although the climate of Asbury Park is mild and tempered, to some extent, by the ocean, artificial heat must always be available. Even during the summer, it is often cool in the evenings, when the place is gayest, and artificial relief is necessary.

With sufficient artificial heating, Asbury Park's activities may be almost as great in the colder months of the year as in Summer, Spring and Fall.

Here is the unusual problem that was presented to the architects of this particular power house, the firm of Warren and Wetmore—a steam plant to provide heat was required and its location was to be adjacent to the building it was to serve. However, the beauty and cleanliness of Asbury Park could not be marred by either the plant or its operation.

The answer that has been given is a notable achievement in plant design. The heating plant has been erected and instead of its being a detriment to the landscape, it has greatly added to the architectural beauty of the community.

In the architectural and economic scheme of Asbury Park, no smoke nuisance could be tolerated. This resort city recognizes cleanliness as an essential to its success.

The designers of the proposed buildings faced the problem of designing a steam plant which would provide an adequate supply of heat without the detriment of smoke. There was even the exact-

ing provision that the whiteness of the visible portion of its camouflaged chimney must not be stained.

The answer to that problem is to be found in the completed Beach Central Heating Plant of the municipality of Asbury Park.

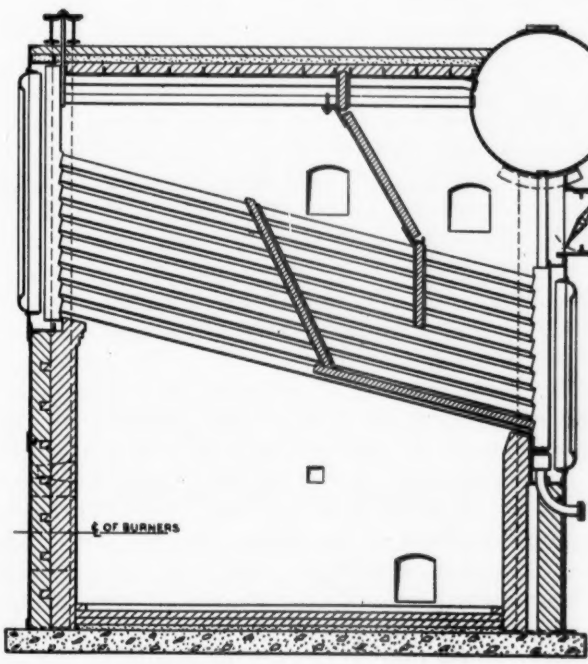
The entire building that adds so greatly to the appearance of the group of structures that have been erected in carrying out the new program for the resort is devoted to the boilers and auxiliary apparatus. The steam that is generated here serves all the buildings controlled by the municipality that either border on the new sixty foot boardwalk or are adjacent to it. The most distant of these is nearly a mile away from the steam plant.

Underneath the lawn to the left of the pool, which is the nearest neighbor of the steam producing plant, are located the oil tanks, which provide a storage capacity of approximately 60,000 gallons of fuel oil. They are, of course, unseen and unknown to the casual visitor.

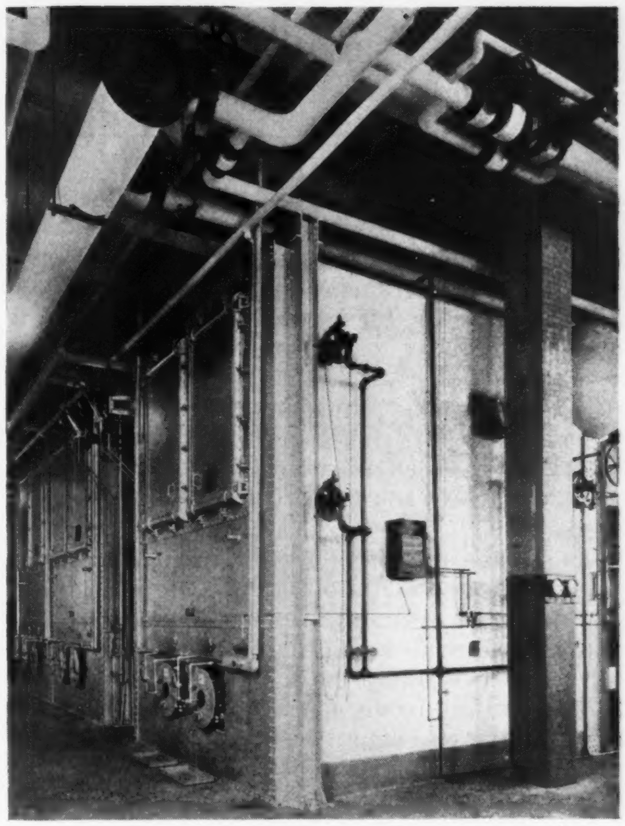
Inside the plant the same brightness and cleanliness prevail. The boilers and auxiliaries are covered with aluminum paint. The illustration was taken when the nearest of the three Walsh and Weidner boilers was on the line, for light can be seen inside the burner register. Each boiler has a heating surface of 3100 sq. ft. and has a capacity of between 600 and 700 developed boiler horsepower. The burners are of the ENCO steam atomizing type, throwing a hollow cone spray of oil. The air is admitted through the burner register in such a manner as to give intimate mixture with the oil, producing a very high efficiency of combustion.

The plant is under automatic combustion control.

The Balanced Draft Regulator can be observed on the side of the boiler in the illustration. Mounted at the rear of the boiler is an operating cylinder, which connects to the draft damper by means of




Sectional elevation of one of the three boiler units



Interior view of new Asbury Park steam plant

a wheel and cable. This regulator maintains the furnace draft at its most efficient point.

Another regulator operates from steam pressure in such a manner that when the pressure drops more oil and a proportionate amount of steam for atomizing are admitted to the burners, and as the steam pressure rises, the opposite movement of this equipment reduces the amount of fuel sprayed into the furnace.

This control equipment is in no sense "all off or all on" for the boiler "floats" on the line, maintaining the steam pressure constant within one or two pounds.

The boilers are equipped with automatic feed water regulators.

This combination of automatic control for both the oil burners and the feed water makes the plant practically automatic in operation. The fireman has nothing to do except to make occasional rounds to see that everything is in order. Theoretically he has the added duty of blowing the soot from the boiler tubes. However, as far as can be learned, this has practically become a lost art with him because of the excellent combustion conditions.

No efficiency figures are obtainable for publication other than that they are around eighty per cent. On the other hand, the entire plant is said authoritatively "to have given uniformly reliable service and high efficiency."

The Beach Central Heating Plant at Asbury Park is eloquent proof of the fact that a steam plant may be practical and economical without being unsightly in appearance and offensive in its operation.

# Mill Drying of Pulverized Coal

## By B. J. Cross

IT is now common practice to dry coal during the process of pulverization. Drying is a surface effect and moisture in the interior of a coal particle must travel to the surface by capillary attraction or similar process. It follows therefore that as the particle is reduced in size and the ratio of surface to volume is increased, the process of drying is much accelerated. Thus, in mill drying, though the coal particle is in the mill only a few seconds, the drying is as effective as that obtained with a much longer exposure of crushed coal in standard dryers.

In a storage system, mill drying is effected by introducing heated air into the mill system in the return air to the mill and discharging an equivalent volume of saturated or nearly saturated air at the mill vent. Obviously the moisture removed from the coal must all be discharged with the air and the amount of drying is limited by the moisture carrying capacity of the vented air.

The amount of circulating air in a mill system is of the order of about two pounds of air per pound of coal. When up to 50 per cent of this amount of air is vented, air temperatures up to 300 or 350 deg. fahr. may be used without undue risk of overheating the coal in the mill. The amount of hot air introduced into the system may be regulated so that the temperature of the vented air does not exceed 130 deg. fahr. This is a safe limit that has been established by practice.

A direct fired mill system may be compared with a storage mill system where 100 per cent of the air used is vented. Drying is therefore much more effective and the temperature limits are higher. Air temperatures up to 400 deg. fahr. may be used and the temperature of the mixture may be 200 deg. fahr. or even higher.

The heat required for drying coal consists of that necessary to evaporate the moisture and to superheat it to the temperature of the mill vent and that used in heating the coal with its residual moisture to that temperature. There is also a small amount of heat required to separate the moisture from coal. It has been established that when dry coal is moistened it absorbs moisture with the evolution of heat. This amount of heat must be supplied to reverse the process. With high moisture coals and lignites this heat may amount to 20 B.t.u. per pound. With bituminous coals this heat is much smaller and is neglected. It is probably more than compensated for by the slight oxidation that occurs in drying of coal.

Heat is supplied to the system in the heated air admitted to the mill and also in the form of mechanical energy delivered to the mill and exhauster. The useful heat in the air is that between its temperature to the mill and the temperature at the mill vent.

The following calculations show the heat requirements for drying 12 tons of coal per hour from 6 per cent to 2 per cent moisture.

| | |
|---|---|
| Coal per hour | 24,000 lb. |
| Moisture in coal (6 per cent) | 1,440 lb. |
| Moisture in dried coal (2 per cent) | 460 lb. |
| Moisture to be removed | 980 lb. |
| Heat to be supplied—B.t.u. | |
| To evaporate moisture | 1,049,500 B.t.u. |
| To heat dry coal | 282,000 B.t.u. |
| To heat residual moisture | 23,000 B.t.u. |
| Total | 1,354,500 B.t.u. |
| Heat supplied mechanical energy 90 per cent of (15 kw. per ton) | 552,900 B.t.u. |
| Heat to be supplied with air | 801,600 B.t.u. |

The total heat of water vapor at vent temperature between 120 and 130 deg. fahr. is between 1112 and 1117 B.t.u. per pound. For the purpose of this calculation, a total heat of 1115 has been assumed. The heat of the water in the coal is taken as 1 B.t.u. per degree of its temperature above 32 deg. fahr. The specific heat of dry coal is assumed at .25.

The chart on the opposite page has been prepared to show the water vapor content at various wet and dry bulb temperature readings or with different percentages of relative humidity. For the convenience of dealing with whole numbers, the weight of water vapor is given in grains. The weight in grains may be converted to pounds by dividing by 7000. The curve for 0 deg. fahr. depression of the wet bulb gives the weight of water vapor for 100 per cent saturation. The weight of water vapor for any relative humidity may be obtained by multiplying the content at saturation by the per cent relative humidity divided by 100.

In the example given, it is shown that to dry 12 tons of coal from 6 per cent to 2 per cent moisture 980 pounds or 6,860,000 grains of moisture per hour must be vented. If the air is delivered to the heater at 75 deg. fahr. and 60 per cent humidity, it will carry 75 grains per pound of dry air. If it is discharged from the vent at 125 deg. fahr., and 83 per cent saturated it will carry 545 grains per pound dry air. The net removal per pound of air will be 470 grains. The air required to remove the 6,860,000 grains of moisture will therefore be 14,600 pounds per hour.

As the heat required is 801,600 B.t.u. per hour the air must carry 54.9 B.t.u. per pound. As its specific heat is .24, the air delivered to the mill must be heated 229 degrees over its vent temperature or to a temperature of 354 deg. fahr. This air temperature is fixed by the chosen temperature and degree of saturation of the vented air. If a lower vent temperature or a lower degree of saturation were assumed, the weight of air required would be increased and its inlet temperature would be lower for the same amount of drying.

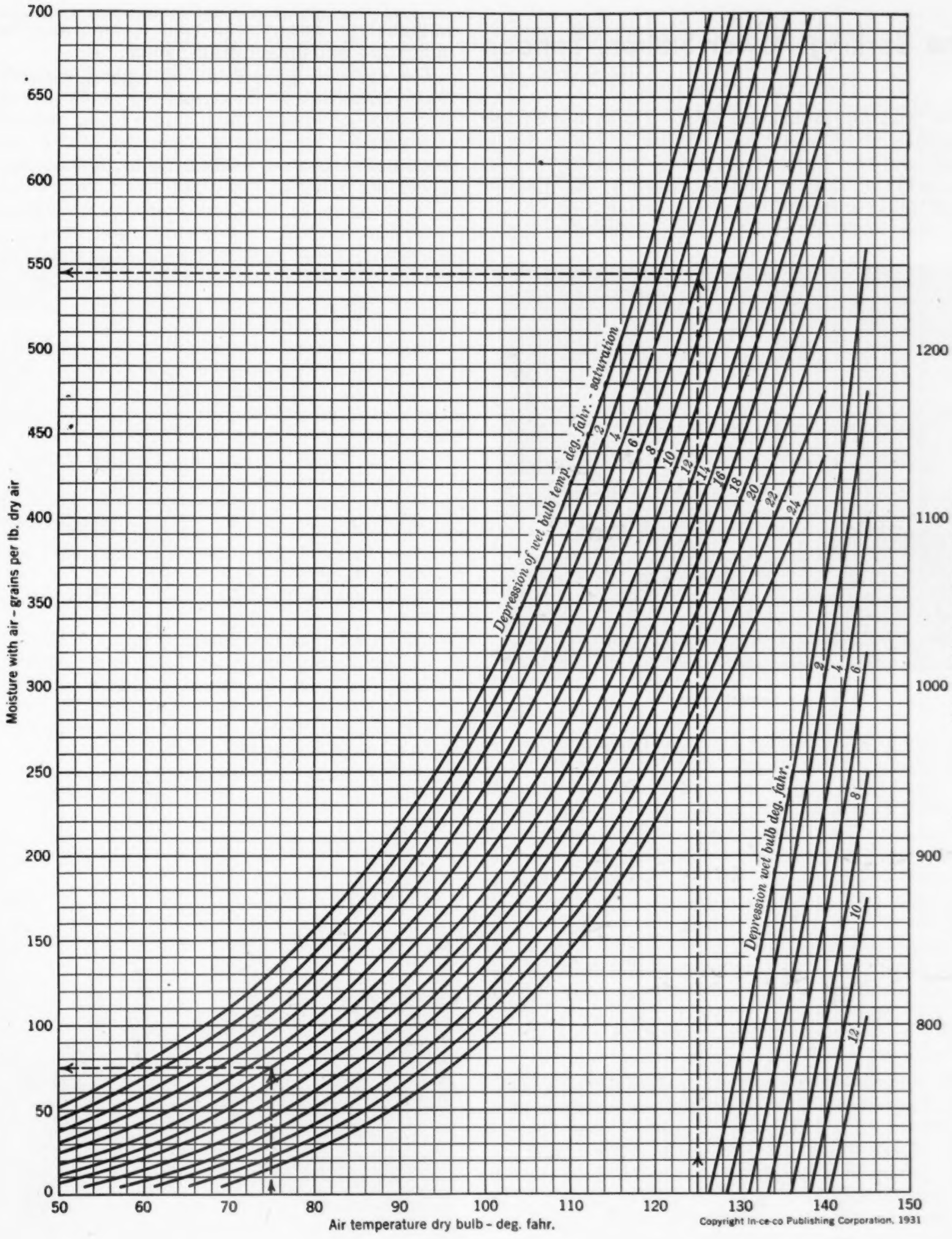


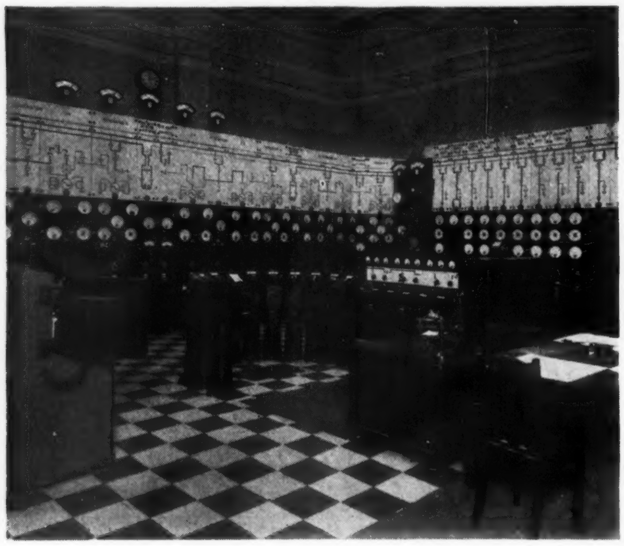

**CHART FOR DETERMINING THE WATER VAPOR CONTENT OF AIR AT DIFFERENT TEMPERATURES AND HUMIDITY**

**No. 23 of a series of charts for the graphical solution of steam plant problems.**

## The Barking Power Station, London

(*Continued from page 45*)

pass, and air preheaters of the Underfeed Stoker multiple plate type. Each boiler has one forced draft and two induced draft fans made by Davidson and Co., Ltd., of Belfast. Each of the induced draft fans, with 150 boiler hp. motor drive, has a capacity of 55,000 cu. ft. per min. (360 deg. fahr.)



**Control room**

capable of maintaining 7½ in. water gage, that is, 110,000 cu. ft. per boiler. The forced draft fan is of the double inlet type, and is driven by a 55 hp. motor giving 67,000 cu. ft. of air (60 deg. fahr.) per min. at 2½ in. water gage. Each of the induced draft fans discharge into a Davidson S.P. centrifugal dust collector, each pair of dust collectors discharging into one steel chimney. For these S.P. collectors, a primary air fan is also used, the complete installation consisting of 10 of these fans, each driven by 70 hp. motors, and discharging 10,000 cu. ft. of air at 16 in. water gage. Five of the boilers have Copes feedwater regulators, while four are operated by Crosby regulators, and one by a Hopkinson Duo regulator.

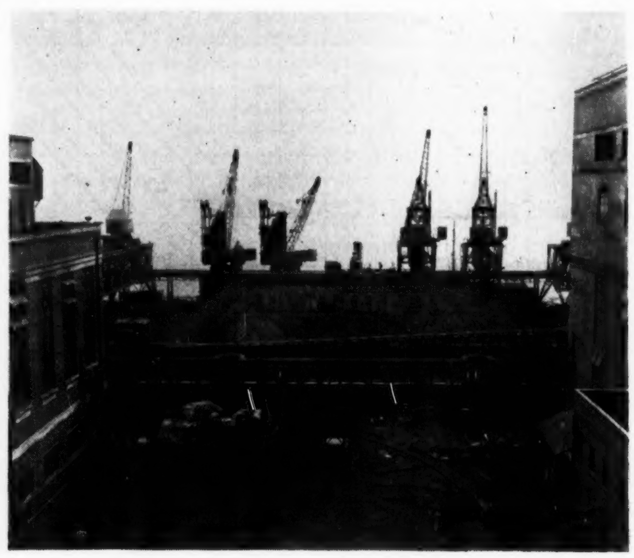
As regards the pulverized fuel equipment, each boiler has its own separate plant, consisting of a Raymond mill of the 6-arm "spider" type, 15 tons of coal per hour capacity, exhaust fans and cyclone separators, overhead storage bunkers for the pulverized coal, feeders, and burners. Each mill is driven by a 200 hp. motor and the mill exhaust fan by an 80 hp. motor. Part of the hot flue gases from the first pass of the boilers is circulated through the mills for drying the coal. Each boiler has 5 motor-driven pulverized fuel feeders each supplying two Lopulco fish-tail burners.

For both boiler houses there is also an extensive equipment of instruments of various kinds, including Cambridge electrical and "W. R." $CO_2$ recorders and indicators, Cambridge multiple point temperature indicators and draft recorders, Kent venturi type meters, Lea coal meters, and Bailey indicating and integrating meters.

The present generating equipment consists of four 40,000 kw. turbo-generators and four 20,000 kw. turbo-generators the turbines being of the Parsons reaction type, with the generators also of Parsons make, running at 3000 r.p.m., 6000 volts and 50 cycles. Further, the 40,000 kw. turbines consist of high-pressure and low-pressure cylinders arranged in tandem on one shaft, and intermediate and low-pressure cylinders on another shaft that is, four cylinders in two lines side by side, each driving a 20,000 kw. generator, constituting cross-compound turbines with two generators.

The steam plant equipment for the third 150,000 kw. extension is to consist of 8 B. & W. Boilers, each having a normal capacity of 256,000 lb. of steam an hour and operating at 625 lb. per sq. in. steam pressure and 800 deg. fahr. superheat temperature. These boilers are to be installed over water-cooled furnaces of the Bailey type and will be equipped with feed water economizers, superheaters and air preheaters. Four boilers will be fired by B. & W. traveling grate stokers, two per boiler, to be supplied by Babcock & Wilcox of London, and the remaining four by Underfeed Type L stokers, supplied by the Underfeed Stoker Company, London. Each boiler will have 22,750 sq. ft. of heating surface, with 1,256 sq. ft. of heating surface in the water-cooled furnace. Additional heating surfaces for each unit are as follows: Superheater, 4,850 sq. ft.; Economizer, 22,176 sq. ft.; Air Preheater, 16,650 sq. ft.

The 2 B. & W. stokers installed under each unit will have a total area of 30 x 22 ft., or 660 sq ft. of



**Coal loading jetty on the Thames**

grate surface, and the Underfeed Type L stokers will have a total area of 30 ft. x 22 ft. 6 in., or a total of 675 sq. ft. of grate area.

An interesting feature is a complete installation of dust collectors of which four are to be of Davidson make and four of Pneuconex make, that is one

(*Continued on page 52*)

# NEWS

**Pertinent Items of Men and Affairs**

## Dr. S. W. Parr Dies

DR. S. W. PARR

Dr. Samuel Wilson Parr, professor emeritus of practical chemistry at the University of Illinois, died May 16 of heart disease. He was seventy-four years old.

Dr. Parr was recognized as one of America's leading authorities on the chemistry of coal. His contributions to chemistry were many, including the discovery of illium, a substitute for platinum, which was named for the University of Illinois.

The method devised by Dr. Parr for determining the heat value of fuels is in wide use both in this country and Europe. He perfected an improved type of calorimeter for determining and recording the heat values of combustible gases and contributed much to research in connection with caustic embrittlement and the crystallization of steel in steam boilers.

Dr. Parr was born in Granville, Illinois, on January 21, 1857. He was graduated from the University of Illinois in 1884 and received his Master's Degree from Cornell University in 1885. Later he studied in Berlin and Zurich. Dr. Parr began teaching in Illinois College in 1885. In 1891 he became professor of applied chemistry at the University of Illinois which position he held until his retirement.

It was practical chemistry that appealed to Dr. Parr most and a great deal of his time was devoted to devising methods whereby chemical discoveries could be used for the benefit of humanity.

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## Riley-Badenhausen Consolidation

The Riley Stoker Corporation, Worcester, Mass., manufacturer of combustion equipment, and The Badenhausen Corporation, Cornwells Heights, Pa., manufacturer of boilers and heat transfer equipment, have announced the consolidation of the two corporations. As a result, the Riley Stoker Corporation is now in a position to furnish complete steam generating units comprising Riley fuel burning equipment and Badenhausen boilers.

A number of installations have already been made with combined Riley-Badenhausen equipment, all of which, however, were sold under separate contracts.

## Fuel Association Will Meet in the Fall

The annual meeting of the International Railway Fuel Association, usually held in May, has been postponed this year until the third week in September, when a two-day business session will be held, without exhibition or entertainment features, September 15 and 16 at the Hotel Sherman, Chicago.

In deference to present reduced business activity and the necessity for economy, it was decided to cut the annual convention from four days to two days and limit the addresses and committee reports strictly to those having a direct bearing on fuel performance, as reflected in increased railway operating efficiency.

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**General Refractories Company,** Philadelphia, Pa., at a recent meeting of the Board of Directors elected the following officers: Burrows Sloan, Chairman of the Board; John R. Sproul, President; E. A. McKelvy, Vice-President and Roger A. Hitchins, Secretary and Treasurer. All of the other officers of the company were reappointed.

## Grindle Acquires Bethlehem Pulverizer

The Grindle Fuel Equipment Company, Harvey, Illinois, a subsidiary of the Whiting Corporation, has purchased the exclusive manufacturing and selling rights to the Bethlehem pulverizer formerly manufactured by the Bethlehem Steel Company.

The Whiting Corporation manufactures pulverizing equipment, power house and industrial cranes, foundry and shop equipment, and automatic stokers.

Other subsidiaries of Whiting Corporation are: Swenson Evaporator Company and Joseph Harrington Company.

•

**Stephens-Adamson Manufacturing Company,** Aurora, Illinois, conveyor and screen manufacturer, has announced that C. H. Adamson, Secretary of the company, will be in direct charge of sales and engineering in the Chicago territory. New and larger district office headquarters have been established at 20 North Wacker Drive, Chicago.

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**Link-Belt Company,** Chicago, announces the appointment of William L. Hartley as District Sales Manager in charge of the Detroit territory with offices at 5938 Linsdale Avenue, Detroit.

Mr. Hartley entered the employ of the Link-Belt Company in 1915 and has been successively identified with the contract, standardization, estimating and sales departments of that organization.

## The Barking Power Station, London

(*Continued from page 50*)

collector for each boiler, through which all the combustion gases will pass to the chimney.

The two "B.T.H." 75,000 kw. turbo-generators are each of the 3-cylinder, single-line type, with 45 stages, and are designed for 569 lb. pressure, and 797 deg. fahr. superheated steam temperature at the stop valve, with vacuum of 29 in. The condensers are of Hick-Hargreaves make.

Noteworthy also at Barking is an experimental installation of a Chloronome apparatus made by the Paterson Engineering Co., Ltd., of London, for the sterilization of the cooling water by the continuous addition of a measured trace of chlorine gas to prevent organic growths on the condenser tubes and allow full vacuum to be maintained. The apparatus at present deals with 2,500,000 gal. of cooling water per hour, in connection with one turbine of 40,000 kw., taking 5 lb. of liquid chlorine per hour. The capacity of this installation however, is sufficient for 3 turbines of 40,000 kw., that is a total of 7,500,000 gal. of water per 24 hr. The amount of chlorine usually required in this connection is about 0.20 to 0.50 parts by weight of chlorine per 1,000,000 parts of water but this naturally depends upon the condition of the water.

Generally, therefore, it would seem these new extensions at Barking have been designed while taking into account the general advances made since 1924 when the first section opened, mainly from the point of view of giving a relatively simple and straightforward yet efficient installation which could be operated with minimum maintenance expense and a high service factor.

Thus reheating is not included although partially operating in the first section. The increase in steam pressure and temperature from 375 lb. and 725 deg. fahr. for the present two sections to 625 lb. and 800 deg. fahr., is along the lines of conservative practice compared with a number of the latest stations. While the boilers have been increased considerably in size—from 68,000 lb. per hour evaporation in the first section and 135,000 lb. per hour in the second section to 256,000 lb. in the third—here again the practice is fairly conservative. Similarly the turbo-generators are now 75,000 kw., instead of 40,000 kw. and 20,000 kw. Traveling grate stokers have been selected in preference to pulverized fuel for reasons more or less peculiar to this plant, i.e., a fuel that is particularly suited to this type of stoker and but moderate fluctation of load which factors permit an efficiency with stokers only slightly lower than that secured with pulverized fuel. In this connection it must be remembered that the general conditions are not the same as in the United States, the average British coal having higher ash and moisture contents than most American coals.

In general, the thermal efficiency of this new section at Barking ought to be about 25 per cent from the raw coal to the switchboard the present station being from 21 to 22 per cent according to the annual returns of the Electricity Commissioner.

In closing, the author wishes to acknowledge his indebtedness to the County of London Electricity Supply Co., Ltd., and to Mr. W. J. H. Wood, Engineer-in-Chief, for the illustrations used in this article.

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## Annual Meeting Stoker Manufacturers Association

AT the annual meeting of the Stoker Manufacturers Association in New York City on May 15, Joseph G. Worker, of the American Engineering Company, was re-elected President; R. C. Goddard, of Combustioneer, Inc., was elected Vice President and F. H. Daniels of the Riley Stoker Corporation, Treasurer.

F. R. Low, Editor Emeritus of Power, was elected an honorary member of the Association at a full meeting of the Executive Committee.

Mr. Worker reported to the Association that stoker sales were holding up to the 1930 level, sales of mechanical stokers in the United States for the first quarter of 1931 being exactly 100 per cent of the sales for the first quarter of 1929.

It was voted that the Association should serve the public more efficiently by further development of stokers for burning coal in the home. The work of the Committee of Ten, composed of representatives of national organizations who are cooperating to collect and interchange educational data pertaining to the burning of coal of both large and household stokers, was endorsed.

The Executive Committee adopted the recommended setting heights for heating boilers equipped with mechanical stokers, prepared by the Mid-West Stoker Association.

It was decided to publish a revised edition of the Condensed Catalog covering all types of stokers manufactured by member companies.

The meeting was attended by representatives of the following companies: American Engineering Co., Philadelphia, Pa.; Auburn Stoker Corp., Auburn, Ind.; Babcock & Wilcox Co., New York City; Burke Engineering Co., Chicago, Ill.; Combustioneer, Inc., Goshen, Ind.; Combustion Engineering Corp., New York City; Detroit Stoker Co., Detroit, Mich.; Flynn & Emrich Co., Baltimore, Md.; Illinois Stoker Co., Alton, Ill.; Laclede Stoker Co.; St. Louis, Mo.; Riley Stoker Corp., Worcester, Mass.; Westinghouse Electric & Mfg. Co., Philadelphia, Pa.; Iron Fireman Mfg. Co., Portland, Ore. Two of these companies, Combustioneer, Inc. and Iron Fireman Mfg. Co., were admitted to the Association during the past year.

The Fall meeting will be held in Atlantic City in October.

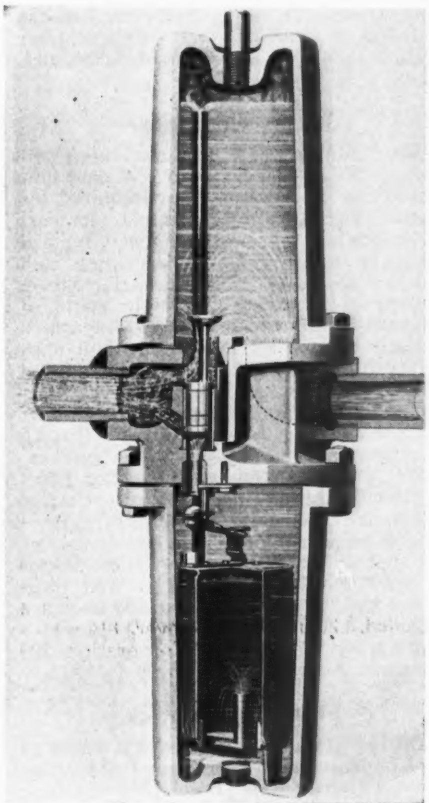
# NEW EQUIPMENT

**of interest to steam plant Engineers**

## New Compound Steam Trap

The new Armstrong Compound Trap was developed by the Armstrong Machine Works, Three Rivers, Michigan, to overcome the troubles often experienced with the ordinary types of piston operated traps. It has few moving parts, is simple in design, and has high capacity for a given diameter of discharge orifice.

The design and construction insure reliable operation practically without attention. Should it become necessary to in-



spect the operating mechanism, all parts are easily accessible without disturbing the inlet or outlet connections. The keynote of its design is extreme simplicity —in the pilot trap there are only two moving parts, the inverted bucket and valve lever; and in the pilot housing, the piston and main valve, which are integral and therefore operate in unison.

The body of the Compound Trap consists of standard Armstrong trap bodies bolted to a piston housing. In the No. 230 series Compound Traps, for pressures up to 250 lb., the piston housing and bodies are made of close-grained semi-steel of high tensile strength containing nickel and chromium. For high temperature, high pressure duty, the bodies are one-piece forgings, while the piston housing is machined from a solid steel billet.

With this construction, the entire trap mechanism is accessible. After removing the receiving chamber body, the piston valve seat can be unscrewed. It is then a simple matter to pull out the main valve and piston, as well as the piston liner.

No springs are used in this new trap. With the vertical piston and liner, the main valve is closed by gravity. Excessive opening of the main valve is prevented by the unique combination of pressure relief port and partial closing of the main discharge port. This makes a water brake that prevents excess opening of the main valve. Large water passages through the trap, and practically straight-line flow, give this trap very high capacity in proportion to the main valve area. Oversize inlet and outlet connections are provided, so that the discharge orifice is the limiting factor of capacity instead of pipe friction. It can be easily demonstrated that a 2 in. Compound Trap with 3 in. pipe connections will handle more condensate than a 2½ in. trap with 2½ in. pipe connections.

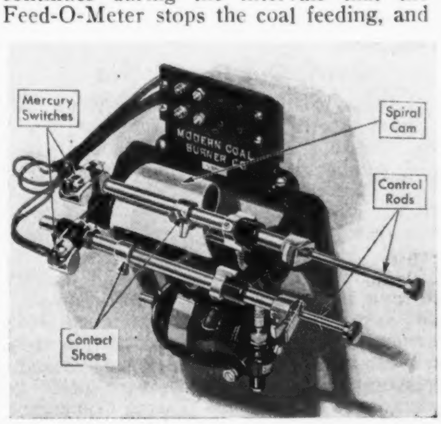
## Automatic Stoker Regulator

The Feed-O-Meter, a device for automatically controlling the feeding rate of mechanical stokers, has been developed by the Modern Coal Burner Company, 3733 Lincoln Avenue, Chicago.

The design of this regulator is based on the idea that for the finest control and greatest economy, an infinite number of firing rates is ideal. The Feed-O-Meter offers a simple and dependable means of obtaining this ideal firing condition and the perfection of heat regulation that goes with it.

The ideal feeding rate of a stoker is found at the point where the stoker runs almost constantly in meeting the given heating requirements. In fact, the only reason for stopping a stoker is found in the fact that the stoker must operate at a higher rate than is necessary to satisfy the thermostat or pressurestat. The ideal feeding rate is therefore just as little above the requirements of the pressurestat or thermostat as is practicable.

The fan which supplies the forced draft for stoker operation is operated by a separate drive and the Feed-O-Meter does not stop the fan. Therefore the draft continues during the intervals that the Feed-O-Meter stops the coal feeding, and




the effect is that of continuous and efficient firing at the ideal rate to meet the given heating requirement.

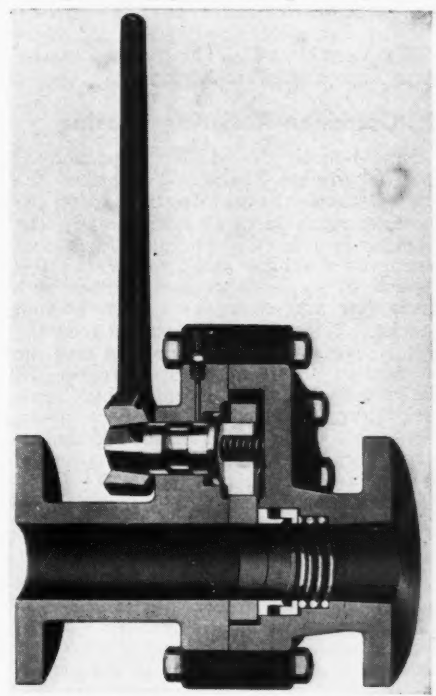
On new installations, the Feed-O-Meter requires only a one speed transmission. In fact, this is standard construction. However, it can also be applied to existing installations where multi-speed transmissions are already in service if conditions should warrant it.

The device is installed in a heavy-gage sheet-metal box, underwriter approved. The lever, or levers, protrude through the side of the box so that they can be operated from the outside.

## Quick Opening Valve

Answering the demand for a quick operating valve for general industrial use, the Yarnall-Waring Company, Chestnut Hill, Philadelphia, has developed a line of Yarway Pretite Valves for general service use. These valves are the quick opening, lever operated, swing gate type having a straight through flow and the unique feature of a new two piece sealing bushing on the inlet side so that, as its name implies, it is "pre-tight."

This new two piece construction of the sealing bushing provides a positive, auto-



matic packing adjustment. The sealing bushing is forced tight against the machined surface of the gate by the line pressure this pressure being applied only on the annular area on the end of the sealing bushing which is not against the disc. A heavy corrosion-resisting spring keeps the sealing bushing tight against the disc or gate when no pressure is applied. The sealing bushing is continually "ground in" in the same manner as is the opposite face of the one piece solid disc as it passes across the seat. This disc is in positive contact with its two seats during the entire opening and closing action.

This new valve is lubricated by means of Alemite bushings, the grease being distributed to the sliding surfaces.

Pretite Valves are available in a wide range of materials—iron, steel, stainless steel, acid bronze, aluminum, etc.

The valves are applicable for use in handling hot liquids at temperatures as high as 1800 deg. fahr. and for a wide range of solutions, such as mine waters, acid solutions, paper sulphite solutions, various salts in solution, hot oils, etc. Sizes are available from ½ in. to 4 in. for pressure ranges up to 225 lb. per sq. in.

# NEW CATALOGS AND BULLETINS

**Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine**

### $CO_2$ Meters

Brown Electric $CO_2$ Meters, both indicating and recording types, are described in new catalog No. 3004. The opening paragraphs discuss the measure of $CO_2$ in the flue gas as an indication of the correctness of combustion conditions, following which are a description of the Brown $CO_2$ Recorder, its principle of operation, design and construction. Numerous application arrangements are illustrated and described and descriptions of the Brown Combined $CO_2$ and Flue Gas Temperature Recorder and the Brown Electric Pyrometer are included. 32 pages and cover, 8½ x 11—The Brown Instrument Company, Philadelphia, Pa.

### Corrosion Resisting Coating

New bulletin No. 1270 "Inspection of Internal Boiler Surfaces" describes the use of Apexior as a protective coating for the internal surfaces of steam boilers, etc. Apexior is a mixture in liquid form consisting of a vehicle and a pigment. It is applied to steel surfaces in contact with hot water and steam in a thin, smooth coating. It prevents contact between the metal surfaces of the equipment and the hot water and steam. Thus corrosion of the protected surfaces is impossible. Some interesting information is given about what to look for when inspecting the internal surfaces of a boiler after a period of regular operation. 4 pages, 8½ x 11—The Dampney Company of America, Hyde Park, Boston, Massachusetts.

### Evaporators

Buflovak Evaporators are described in a handsome new bulletin No. 264. While these evaporators are widely used for concentrating various products in the chemical and manufacturing industries, they are also applicable to the making of distilled water and make-up water. Many illustrations and diagrams in color show the principles of design and construction and charts and general performance data are included. 28 pages and cover, 8½ x 11—Buffalo Foundry and Machine Company, 1635 Fillmore Avenue, Buffalo, New York.

### Feed Water Chemical Control

Data sheets, recently issued, describe the Permutit Type B Electro-Chemical Feed, which finds its widest application in conjunction with lime soda water softeners although it can also be used for the feeding of chemicals for any other water treating purposes. The device consists essentially of a meter which makes electrical contact, starting the motor of the chemical feed device when a predetermined amount of water has passed the meter. The feed device goes through a predetermined cycle, automatically stopping the feed motor when the amount of chemical for which the meter is set has been introduced. 4 pages, 8½ x 11—The Permutit Company, 440 Fourth Avenue, New York.

### Indicating Thermometers

Foxboro Dial Type Indicating Thermometers are illustrated and described in attractive new bulletin No. 148-2. These instruments are available in a wide range of varieties and types suitable for practically every method of mounting. In addition to descriptions of the instruments themselves, the booklet contains valuable information on dials, bulbs, tubing, gage boards and other details relating to temperature measurement. Numerous pictures of typical applications are included and specifications and dimension sheets are given. 32 pages and cover, 8½ x 11—The Foxboro Company, Foxboro, Massachusetts.

### Liquid Level Controller

The Mercon Liquid Level Controller, recently placed on the market, is described in new bulletin No. 4-C. This controller incorporates certain desirable new features: 1. the capacity of the valve can be re-adjusted to meet actual operating conditions without taking the controller out of service; 2. the level maintained can be re-located to a new point without taking the controller out of service; 3. the distance between the float chamber and valve body can be easily changed in the field; 4. every part of the controller is open to pressure—no stuffing boxes or packing; 5. all working parts are of stainless or nitrided steel as required. 4 pages, 8½ x 11—The Mercon Regulator Company, 1 La Salle Street, Chicago, Illinois.

### Pressure Regulating Valves

The Spence line of regulating valves is presented in a new and attractive looseleaf binder. Pressure regulators, temperature regulators and various types of control valves and equipment are included. The apparatus and its application are well illustrated and specifications and dimension sheets are included, together with valuable information on steam flow and control. 56 pages and binder, 8½ x 11—Spence Engineering Company, 110 East 42nd Street, New York.

### Quick Opening Valves

Bulletin P-501 presents the new line of Yarway Pretite Valves for general service. These valves are of the lever operated, swing gate type. When open, these valves present a straight line through passage for unobstructed flow and are free from recesses for cumulation of deposits. Alemite lubrication of steel and disc insures easy operation and quick shutting off of flow. The valves are available in a wide range of materials suitable for practically any industrial condition and in sizes from ½ in. to 4 in. inclusive and pressures up to 225 lb. per square inch. 4 pages, 8½ x 11—Yarnall-Waring Company, Chestnut Hill, Philadelphia, Pennsylvania.

### Small Tubing and Fittings

New bulletin No. 13 describes Dieform Compression Fittings for use with soft annealed copper tubing in the installation of metering and control equipment. Copper tubing and compression fittings have many advantages over standard piping with threaded joints. Their use eliminates the use of threaded piping during installation, reduces the number of joints required and assures leak-proof connecting lines at minimum cost. The fittings are available in brass, monel metal or steel and either copper or steel tubing may be used. Dimension sheets and price lists are included. 16 pages, 8½ x 11—Bailey Meter Company, 1050 Ivanhoe Road, Cleveland, Ohio.

### Steam Generator

New catalog SG-1 presents the Combustion Steam Generator, a complete unit embodying all of the elements required for steam generation in a simple, compact arrangement, assuring the highest practical efficiency with minimum operating and maintenance costs. The Combustion Steam Generator is available in eight standard sizes providing a wide range of capacities for any desired steam pressure and temperature. Pulverized fuel is introduced at the four corners of a completely water-cooled furnace and is burned with intense turbulent mixing action, the gases leaving the superheater at the top of the furnace, thence through a bank of convection tubes and finally through a plate type preheater and to the chimney. A novel arrangement provides for regulating the temperature of the superheated steam under all conditions of operation. The catalog is well illustrated and dimensions of various sizes are included. 20 pages and cover, 8½ x 11—Combustion Engineering Corporation, 200 Madison Avenue, New York.

### Steam Specialties

During the past few months, a series of new bulletins have been issued describing various Detroit steam specialties and their application. These specialties include control valves, constant level valves, oil control valves, solenoid operated valves, low water cutout and pressure control strainers, etc. 8½ x 11, for mounting in looseleaf folder—Detroit Lubricator Company, Detroit, Michigan.

# Boiler, Stoker and Pulverized Fuel Equipment Sales

## BOILER SALES

Orders for 630 boilers were placed in March, according to reports submitted to the Bureau of the Census by 73* manufacturers.

| Month | 1930 Number | 1930 Square feet | 1931 Number | 1931 Square feet |
|---|---|---|---|---|
| January | 942 | 1,081,749 | 598 | 576,723 |
| February | 873 | 938,906 | 516 | 622,343 |
| March | 977 | 1,263,709 | 630 | 664,784 |
| Total (3 mo.) | 2,792 | 3,284,364 | 1,744 | 1,863,850 |
| March | 977 | 1,263,709 | | |
| April | 1,017 | 1,070,093 | | |
| May | 1,283 | 1,329,748 | | |
| June | 1,360 | 1,588,553 | | |
| July | 1,309 | 1,410,096 | | |
| August | 1,371 | 1,356,751 | | |
| September | 1,254 | 1,282,388 | | |
| October | 1,189 | 851,525 | | |
| November | 777 | 709,322 | | |
| December | 814 | 587,053 | | |
| Total (Year) | 13,166 | 13,469,893 | | |

Totals for First 2 Months and New Orders, by Kind, Placed in March, 1930-1931

| Kind | 1930 No. | 1930 Sq. ft. | 1931 No. | 1931 Sq. ft. | March, 1930 No. | March, 1930 Sq. ft. | March, 1931 No. | March, 1931 Sq. ft. |
|---|---|---|---|---|---|---|---|---|
| Stationary: Total | 2,730 | 3,061,036 | 1,682 | 1,673,819 | 966 | 1,246,773 | 602 | 583,757 |
| Water tube | 280 | 1,620,955 | 169 | 793,088 | 112 | 758,230 | 51 | 248,034 |
| Horizontal return tubular | 210 | 293,495 | 112 | 134,712 | 72 | 92,153 | 40 | 43,667 |
| Vertical fire tube | 325 | 105,750 | 172 | 46,535 | 118 | 35,476 | 53 | 14,178 |
| Locomotive (not railway) | 52 | 38,236 | 15 | 10,343 | 29 | 23,302 | 6 | 5,207 |
| Steel heating [1] | 1,479 | 653,916 | 998 | 489,594 | 515 | 226,841 | 367 | 192,320 |
| Oil country | 219 | 245,794 | 135 | 148,700 | 70 | 79,131 | 56 | 60,549 |
| Self contained portable [2] | 128 | 87,281 | 66 | 39,259 | 40 | 27,821 | 24 | 16,138 |
| Miscellaneous | 37 | 15,609 | 15 | 11,588 | 10 | 3,819 | 5 | 3,664 |

[1] As differentiated from power.
[2] Not including types listed above.
* One establishment whose data were included in previous reports has gone out of business.

## MECHANICAL STOKER SALES

March stoker sales, reported to the Bureau of the Census by the 11 leading manufacturers, totaled 63 stokers of 17,993 hp.

| Year and Month | TOTAL No. | TOTAL H.P. | INSTALLED UNDER Fire-tube boilers No. | Fire-tube boilers H.P. | Water-tube boilers No. | Water-tube boilers H.P. |
|---|---|---|---|---|---|---|
| **1929** | | | | | | |
| January | 97 | 42,392 | 36 | 5,835 | 61 | 36,557 |
| February | 80 | 31,554 | 26 | 3,933 | 54 | 27,621 |
| March | 117 | 42,432 | 42 | 6,369 | 75 | 36,063 |
| Total (3 Mo.) | 294 | 116,378 | 104 | 16,137 | 190 | 100,241 |
| Total (Year) | 1,716 | 599,585 | 706 | 102,515 | 1,010 | 497,070 |
| **1930** | | | | | | |
| January | 53 | 13,198 | 24 | 2,872 | 29 | 10,326 |
| February | 73 | 22,648 | 26 | 3,732 | 47 | 18,916 |
| March | 89 | 32,403 | 45 | 6,128 | 44 | 26,275 |
| Total (3 Mo.) | 215 | 68,249 | 95 | 12,732 | 120 | 55,517 |
| April | 108 | 35,903 | 46 | 6,984 | 62 | 28,919 |
| May | 96 | 31,956 | 41 | 5,703 | 55 | 26,253 |
| June | 151 | 47,803 | 70 | 10,100 | 81 | 37,703 |
| July | 150 | 37,761 | 83 | 11,434 | 67 | 26,327 |
| August | 115 | 29,988 | 61 | 10,587 | 54 | 19,401 |
| September | 128 | 42,899 | 71 | 9,186 | 57 | 33,713 |
| October | 92 | 38,276 | 46 | 5,148 | 46 | 33,128 |
| November | 71 | 21,103 | 41 | 5,731 | 30 | 15,372 |
| December | 53 | 11,726 | 35 | 5,307 | 18 | 6,419 |
| Total (Year) | 1,179 | 365,664 | 589 | 82,912 | 590 | 282,752 |
| **1931** | | | | | | |
| January | 85 | 25,902 | 40 | 6,719 | 45 | 19,183 |
| February | 67 | 14,249 | 37 | 5,326 | 30 | 8,923 |
| March | 63 | 17,993 | 27 | 4,509 | 36 | 13,484 |
| Total (3 Mo.) | 215 | 58,144 | 104 | 16,554 | 111 | 41,590 |

## PULVERIZED FUEL EQUIPMENT SALES

March orders for coal pulverizers as reported to the Bureau of the Census aggregated 19 pulverizers having a total capacity of 189,250 lb.

| Year and Month | STORAGE SYSTEM — PULVERIZERS: Total Number | No. for new boilers, furnaces and kilns | No. for existing boilers | Total capacity lb. coal/hr.: For contract | Based on New River coal, 3% moist | BOILERS: Number | Total sq. ft. steam generating surface | Total lb. steam per hour equivalent | DIRECT FIRED OR UNIT SYSTEM — PULVERIZERS: Total Number | No. for new boilers, furnaces and kilns | No. for existing boilers | Total capacity lb. coal/hr.: For contract | Based on New River coal, 3% moist | BOILERS: Number | Total sq. ft. steam generating surface | Total lb. steam per hour equivalent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FOR INSTALLATION UNDER WATER-TUBE BOILERS** | | | | | | | | | | | | | | | | |
| 1931 | | | | | | | | | | | | | | | | |
| January | 2 | 2 | .. | 60,000 | 88,000 | 1 | 51,177 | 704,000 | 8 | 4 | 4 | 40,500 | 55,300 | 9 | 42,970 | 412,675 |
| February | 1 | .. | 1 | 40,000 | 50,000 | 1 | 29,100 | 375,000 | 2 | 2 | .. | 8,000 | 8,500 | 1 | 7,570 | 75,000 |
| March | 2 | 2 | .. | 60,000 | 60,000 | .. | ...... | ...... | 13 | 13 | .. | 122,000 | 143,000 | 8 | 93,960 | 1,404,000 |
| Total (3 mo.) | 5 | 4 | 1 | 160,000 | 198,000 | 2 | 80,277 | 1,079,000 | 23 | 19 | 4 | 170,500 | 206,800 | 18 | 144,500 | 1,891,675 |
| **FOR INSTALLATION UNDER FIRE-TUBE BOILERS** | | | | | | | | | | | | | | | | |
| 1931 | | | | | | | | | | | | | | | | |
| January | .. | .. | .. | ...... | ...... | .. | ...... | ........ | 6 | .. | 6 | 6,000 | 6,750 | 6 | 7,500 | 53,350 |
| February | .. | .. | .. | ...... | ...... | .. | ...... | ........ | 3 | .. | 3 | 2,250 | 2,250 | 3 | 3,000 | 22,350 |
| March | .. | .. | .. | ...... | ...... | .. | ...... | ...... | 2 | 1 | 1 | 2,750 | 2,750 | 1 | 3,004 | 22,500 |
| Total (3 mo.) | .. | .. | .. | ...... | ...... | .. | ...... | ........ | 11 | 1 | 10 | 11,000 | 11,750 | 10 | 13,504 | 98,200 |

# COMBUSTION

## GENERAL INDEX OF EDITORIALS AND ARTICLES

### (Vol. 2, No. 1, July, 1930, to and including Vol. 2, No. 12, June, 1931)

### Feature Editorials—



### Editorials—



### Articles—

## Authors—

*(Continued on page 61)*

# BOOKS

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## 2 Corrosion

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Price $6.00

The book brings you a systematic authoritative representation of the theory of corrosion and a detailed description of methods of preventing corrosion. It deals particularly with the ferrous metals.

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*By W. E. Groume-Grjimailo*

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This is a particularly informative and authoritative reference on the subject of combustion gases. Its contents include a practical discussion of the principles for the rational construction of furnaces. The reading and study of this valuable book should lead to many improvements in the art of heating and utilizing of heat.

## 4 Steam, Air, and Gas Power

*By W. H. Severns and H. E. Degler*

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This book has been prepared as an elementary text for use in courses dealing with Heat Engineering, where only a limited amount of work in the subject can be included. The aim has been to describe briefly and clearly, typical and representative equipment and to explain the theory of such machines and devices.

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A mature treatment of mathematics for practicing engineers. A complete treatise on engineering mathematics from arithmetical computations to partial and multiple integration—a mature explanation for practicing engineers of the principles and methods of those phases of mathematics which are especially important in engineering work.

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*By P. J. Kiefer and M. C. Stuart*

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In contents, arrangement of matter and method of treatment, this is something of a departure from standard texts on the subject. The authors have endeavored to give the reader a better and more practical understanding of fundamentals. Means and methods for the utilization of heat energy have advanced so rapidly in recent years that a sound grasp of fundamentals has become a practical necessity. This book will be of great assistance to those who wish to acquire a thorough understanding of the principles of thermodynamics.

## 7 Electric System Handbook

*By C. H. Sanderson*

1167 Pages Price $5.00

This book answers the increasing demand for a handbook which will tell the story of the electric system as a whole, in logical sequence and in a simple form readily understandable by everyone whether he possess a technical education or not.

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## 9

# COMBUSTION

## BOUND VOLUME NUMBER TWO

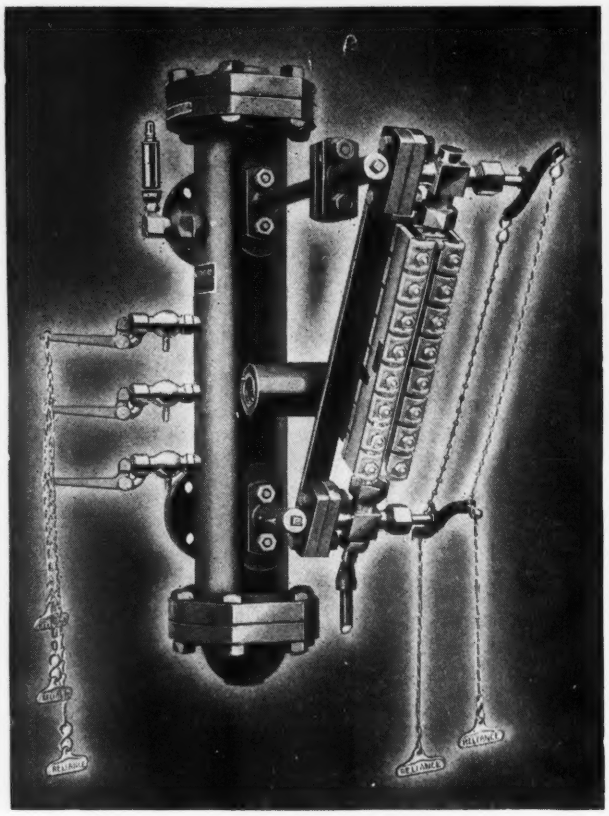
*July 1930 to June 1931*

Orders are now being taken for bound copies of Volume No. 2 of COMBUSTION Magazine. This volume, handsomely bound in buckram covers will contain the second twelve issues of COMBUSTION from July 1930 to June 1931 inclusive.

Price: $5.00 if order is received prior to July 1. Thereafter the price per volume will be $6.00.

# GENERAL INDEX

*(Continued from page 58)*



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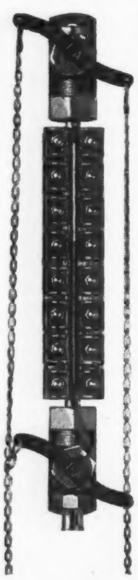

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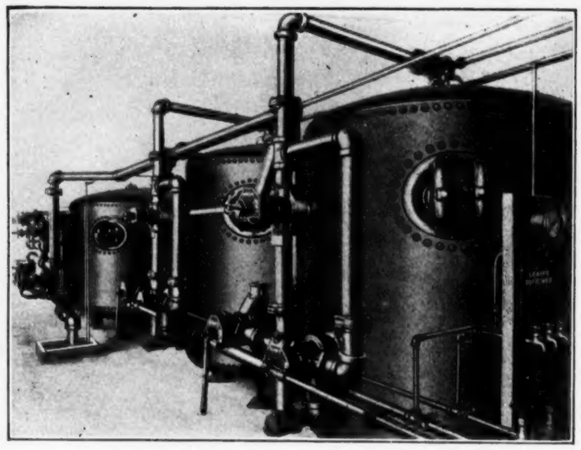

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THESE plants cover a broad field, including vegetable canning factories, flour mills, sugar refiners, producers of baking powder, yeast, salt, condensed milk, etc.

The variety in plant size, kind of water and operating conditions is even broader than the variety of products because one may safely say that in no two of these plants are conditions identical.

However, despite the wide variety of products, water and operating conditions, these 156 plants all have one thing in common—the K.W.S. System of feedwater conditioning.

Some of these plants are quite small, others large; some are old and some the last word in modern engineering; some treat internally and some externally; they are scattered throughout the United States, Canada and Cuba; but the K.W.S. System is so flexible, and adaptable that it takes care of them all. And this is only one specialized group of our customers. The total number runs into thousands.

### *The K. W. S. System is easy to understand*

While you might think that any system to meet such a variety of conditions would have to be complicated, the K.W.S. system is in reality very easy for the average engineer to understand and control. A testing kit is of course necessary, but the tests are quickly learned under our supervision and easily made. You make the tests and report to us on post cards which we supply gratis. Our Service Department advises you immediately if any change in treatment is necessary. In other words your plant is under the supervision of experts constantly at a cost no greater (and in many cases less) than the previous cost of treating.

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The K.W.S. System is constantly on guard against scale formation, carry-over, (foaming), corrosion and caustic embrittlement. These problems, all due to feedwater, can be controlled only by constant watchfulness. If not controlled, the cost of power plant operation is high and constant trouble is encountered. That is why the K.W.S. System has been so widely adopted. It has reduced operating expenses all along the line (fuel consumption, tube replacement, boiler cleaning, lubrication, etc.) Boilers are kept on the line longer, boiler cleaning is in most cases a matter of washing out, overall efficiency has increased and everyone concerned is happier.

Wouldn't you like to know whether this system can be adapted to your plant? It will cost you a 2 cent stamp to find out. Use the coupon below.

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# How continuous boiler blow-off *with heat recovery* will save you money

### A TYPICAL SAVING

One boiler, 400 lb. gauge, average evaporation 100,000 lb. per hour, 100% make-up. Make-up temperature, 60 deg. F.

Allowable concentration in boiler salines, 3000 ppm. Total solids in make-up, 200 ppm.

Blow-off required ........ $\frac{200}{3000 - 200}$ x 100,000 = 7150 lbs. per hr.

Temperature of hot blow-off leaving boiler ........ = 448 deg. F.
Temperature of blow-off leaving heat exchanger ..... = 80 deg. F.
Heat recovered per pound of blow-off ........... = 378 B.t.u.
With coal of 13,000 B.t.u. per lb., and 75% boiler efficiency, this is equivalent to ......3.325 tons per day
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*Permutit Continuous Boiler Blow-off Equipment, with Heat Recovery, for this plant would cost from $2,400 to $3,600. The investment returns from 150% to 200% per year.*

DO YOU know that you can have the advantages of continuous blow-off and save money at the same time? Permutit Continuous Boiler Blow-off Equipment, with Heat Recovery, usually pays for itself in 6 months to a year, as the calculation in the box above shows.

Haphazard blow-off will not maintain the best conditions for steam production. Continuous blow-off in a small stream will.

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Write for a free copy of "Permutit Continuous Blow-off Systems," a 20-page booklet which describes the equipment, discusses the benefits it brings to you, and shows various types and arrangements. No obligation—just drop us a line.

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Manufacturers of all types of Zeolite, Hot and Cold Lime Soda, Lime-Barium Water Softeners—Sand Filters—Iron, Oil and Manganese Removing Filters—Continuous Boiler Blow-off Equipment—Ranarex $CO_2$ Indicators and Recorders—Other Power Plant and Water Treating Specialties.

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# THE SAME OPPORTUNITY IS AVAILABLE TO YOU

EACH plant presents an individual case, of course, but Sirocco Dust Collectors installed in *your* plant will curtail erosion of machinery, cut down on repairs, make equipment last longer and enable your plant to operate as nearly 100 per cent efficiently as possible.

Write us for details on how to obtain and send a dust or material sample suitable for testing in our laboratory. Or ask for our Bulletin 1724. No obligation or cost.

American Blower Corp. Sirocco Trade Mark Detroit, Mich.

**A 100 per cent Sirocco installation with a Sirocco Dust Collector and a Sirocco Induced Draft Fan insures a mechanical draft installation which meets most effectively all the requirements of modern coal-fired boiler practice.**

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MANUFACTURERS OF ALL TYPES OF AIR HANDLING EQUIPMENT SINCE 1881 (1168)

# 3 TIMES *the insulating* POWER

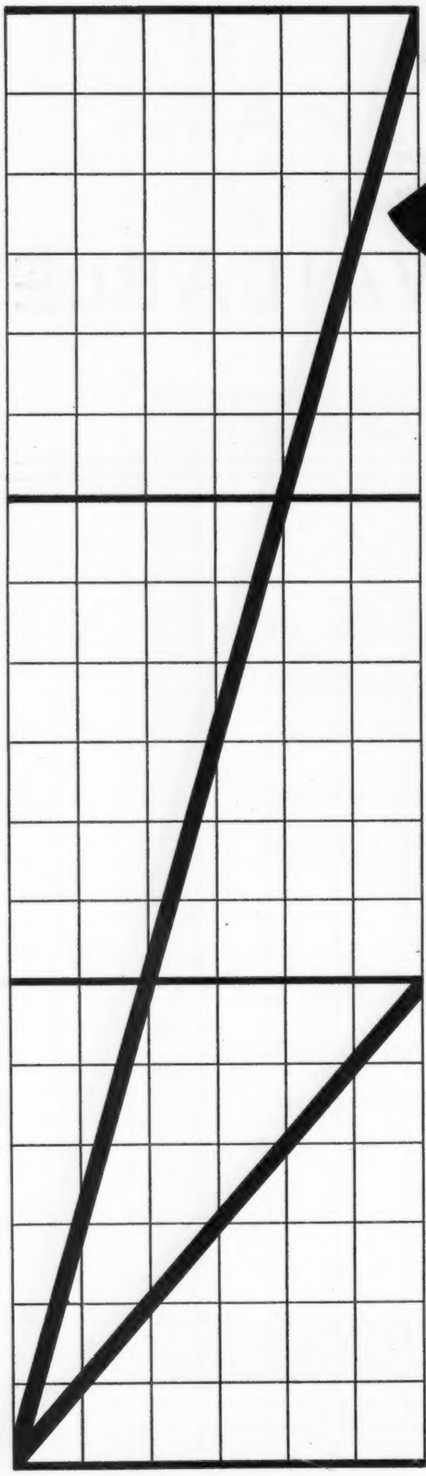
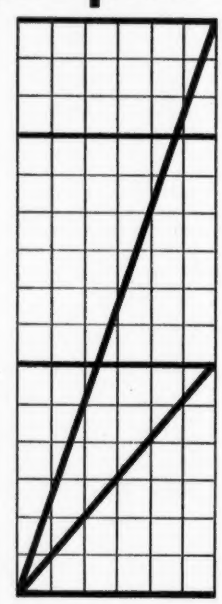


Figure it out any way you please, you can accomplish more with STIC-TITE than with any other single insulating cement. In first cost per job, in heat saving ability, and reclaimability, STIC-TITE will do more at a lower cost per job than any other heat insulating cement. In heat saving alone, STIC-TITE is more than three times as efficient as common asbestos cement. In covering power, STIC-TITE covers more than two and one-half times the area than can be covered, with equal thickness, by the same weight of common asbestos cement. In every way this material is a super-economical heat insulating cement.

**More than**

**2½ times the coverage per pound**



Mechanically, STIC-TITE is also very efficient. On average jobs no reinforcement is necessary because STIC-TITE always sticks. It clings to any clean surface, hot or *cold* and never lifts or pulls away. Whether applied by hand, with a trowel, or with a gun, the result is always the same—a uniformly perfect covering of the most efficient heat insulating cement known today.

STIC-TITE cannot spoil in storage; why not have a good supply on hand, for economy if for no other reason.

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**50 Church St., New York, N. Y.**
**Warehouses in**
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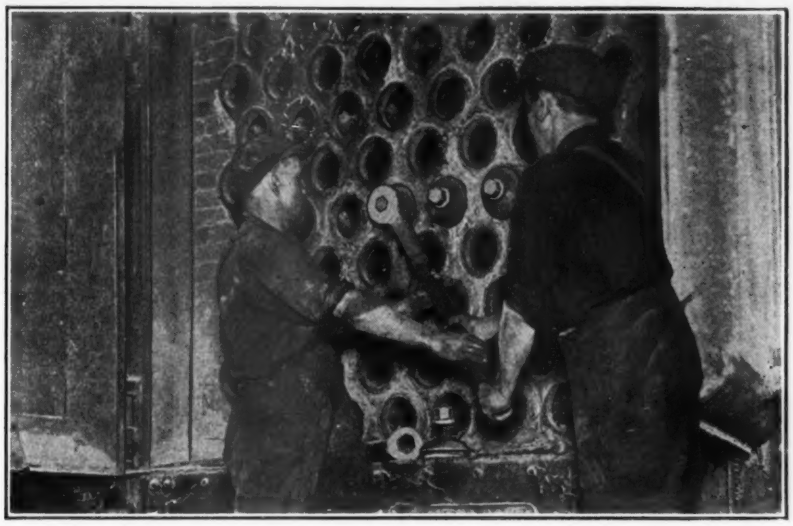
*Made by The Makers of R & E # 3000 MOLDIT and MOLDIT-A*

# STIC-TITE

Patent Applied For

# BOILER *shut-downs reduced from* 17 *to* 4 *times* A YEAR



Two big advantages have accrued to a mid-western tile works that installed a Permutit Zeolite Water Softener in the summer of 1929: (1) They reduced boiler shut-downs from 17 times a year to only 4 times a year; and (2) they have saved approximately 25 per cent of their boiler fuel.

Their own statement about the benefits of Permutized Water is as follows:

" . . . we installed a Permutit Water Softener in our plant fourteen months ago, and have found it satisfactory and economical. It has enabled us to run our boilers for as long as three months without shutting them down . . . Prior to that time, we could not operate them longer than three weeks on account of scale formation in the boilers, feed water line, and feed water heater.

"Our feed water heater formerly was cleaned every three months, and since we have installed the softener, we have only cleaned it once in fourteen months.

"We estimate that we have saved about 25 per cent on our boiler fuel bill since installing the softener."

. . .

Similar benefits are open to you. It costs nothing to get the facts—send for "Reducing Fuel and Boiler Plant Operating Costs," a booklet you will find interesting as well as instructive. No obligation, of course—use this convenient coupon.

THE PERMUTIT COMPANY
440 Fourth Avenue, New York, N. Y.

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*Water Treating Equipment*

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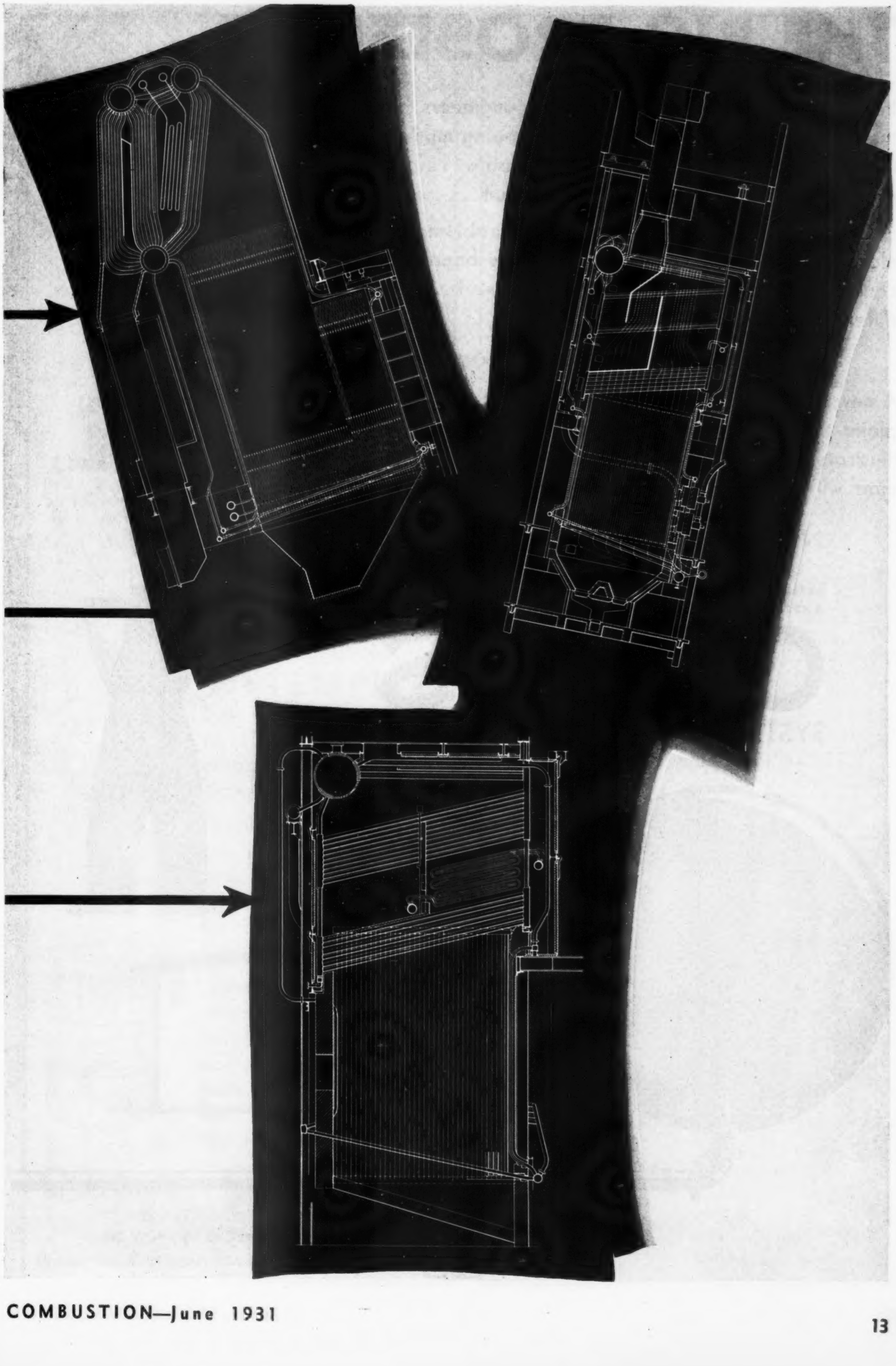

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